Drip Irrigation to Increase Hedgerow Fruit Trees Growth of Alley Cropping in Highland Rainfed Agricultural System

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Abstract

Drip irrigation system was applied in combination with the alley cropping to solve the problem of fruit tree damage during the dry season, increase water use efficiency and productivity of the hedgerow-fruit trees planted on sloping highland rainfed agriculture. Drip irrigation was designed on the basis of engineering principle with low cost investment and high efficiency system. Rainwater was collected in the cylindrical containers set at the upper top part of the experimental plots. Watering from the drip irrigation system was supplied to each planting pit under gravitational force. The amounts of water collected and supplied to each fruit tree were calculated on the basis of the actual water use or evapotranspiration of the fruit tree in the hedgerows during the dry season (January-May). In addition, hydrophilic polymer was also applied to increase the water holding capacity within the root zone before drip irrigation experiment. The experiment was designed as a completely randomized design (CRD) with four replications of 4 practices, (i) non-irrigation, (ii) non-irrigation with polymer using, (iii) drip irrigation and (iv) drip irrigation with polymer using. The effects of drip irrigation on total stored soil water, plant growth and some soil properties were compared with the effects of non-irrigation and polymer application. The results showed that drip irrigation gave substantially higher amount of stored soil water within 1 m soil depth than that of the non-irrigation. However, combination effect of drip irrigation and hydrophilic polymer tended to give the highest stored soil water throughout the experimental periods compared to either drip irrigation or non-irrigation only. During the dry season, the stored soil water under drip irrigation was significantly increased whilst it was decreased under non-irrigation. Fruit trees without drip irrigation were withered and some were died. The results also showed that the plant canopy and height of fruit trees under drip irrigation were growing better than those without irrigation. Vegetative growth of mango, lemon, star apple, guava and sapodilla under drip irrigation were higher than those under non-irrigation at 32, 80, 38, 55 and 20%, respectively. Therefore, the drip irrigation for fruit trees during the dry season, using the rainwater harvested in the rainy season, could be the best strategy for decreasing fruit tree damage and increasing the growth rate excellently which enhances the efficiency of cultivation on sloping land to conserve soil, water and environmental sustainability.

Keywords: drip irrigation, alley cropping, hydrophilic polymer

Introduction

Shifting cultivation is the traditional highland rainfed agricultural system consisted of slash and burn, which has caused problems of soil erosion, leading to degrade soil fertility, poor crop productivity, decreasing ecological environmental quality and highlander's economy for several decades.

Alley cropping system for soil and water conservation on sloping land has been used to solve the problems which may be widely adopted among the highlanders in northern Thailand. The alley cropping was applied to land management for the multiple cropping as field crop or vegetable combined with fruit tree hedgerow or perennial plant. This procedure was used to reduce soil erosion and monoculture cropping, and to increase the forest area, diversity of plants and products, and farmers' income (Panomtaranichagul, Stahr, Fullen, Supawan, & Srivichai, 2010b, p. 15). However, the problem of alley cropping was damage of some fruit trees in the hedgerow during the dry season (January-April). Particularly, growth of the new planted fruit trees were limited by water stress, leading to decreased yield and quality of fruit production.

The drip irrigation system was used in combination with the alley cropping to solve the problem of fruit tree damage during the dry season, increase water use efficiency and productivity of the hedgerow-fruit trees planted on sloping highland rainfed agriculture. This method was slow and often watering to plant with small amounts of water. The important aim of this water supply was to maintain sufficiency of the available soil moisture in the root zone. The advantages of drip irrigation are water saving and a huge benefit of plants because water accesses to the root zone directly, instead of losing in between the plant rows, leading to decrease weed problem. Its disadvantage is a clogging of emitters which may require the high maintenance and good water filtration (Keller, 1990). Drip irrigation was designed on the basis of engineering principle with low cost investment and high efficiency system. Furthermore, the rainwater harvesting system for dripping irrigation during the dry season was simple, practical and economical. In addition, adding water absorbent material as hydrophilic polymer into the soil was expected to increase soil water holding capacity in the root zone. The popular hydrophilic polymer used in agriculture is PAM (Poly-Acrylamide), which is a byproduct of the plastic manufacturing industry. The dry polymer is the small powder or white flake, and will be expanded as jelly when wetted and the volume are increased to 300-500 times of the dry weight (Science and Technology Knowledge Center, 2010). Therefore, application of hydrophilic polymer in the rainfed highland agricultural system, to improve drip irrigation efficiency for the hedgerow-fruit trees of alley cropping may help to reduce the irrigation frequency and water during the dry period, as well as increase the water holding capacity of soil, and crop water use efficiency.

This research aimed to reduce the risk of fruit tree damage during the dry season, and to increase water use efficiency and productivity of the hedgerow-fruit trees planted on sloping highland rainfed agriculture. The supplementary drip irrigation to the fruit tree hedgerow of alley cropping in highland rainfed agricultural system during the dry season may help in successful growing non-drought tolerant plants and various fruit tree varieties with better productivity, leading to the improved income and economy for the stakeholders including improvement of soil, water and environment quality. These may enhance the farmers to have motivation in using the alley cropping for gaining the sustainable highland rainfed agriculture.

Materials and Methods

1. Location and experimental plot preparation

The experimental site was located in Banthuan village, Bantab sub-district, Mae Chaem district, Chiang Mai province, at hill slope of 78% (37°), 18° 31’ 05” N latitude, 98° 17’ 30” E longitude and 1,245 m altitude. The soil texture in this location was the fine texture. The experimental plot was divided into the fifteen 5x30 m sub-plots, which used to be a studied site for conservative cultivation method (Panomtaranichagul, Nareubal, Supawan, & Srivichai, 2010a, p. 16). Each alley cropping plot was divided into 2 sections of 15 m down the slope with 3 m wide of the fruit tree hedgerows. The 4 sub-plots of alley cropping were selected for this study. Each fruit tree hedgerow consisted of 5 fruit trees varieties with 2-rows planted zigzag by 2x2 m spacing and planted as individual basin with 0.5-1 m diameter (FAO, 2010). The hedgerow fruit trees were mango (*Mangifera indica* L.), lemon (*Citrus aurantifolia*), star apple (*Averrhoa carambola* L.), guava (*Psidium guajava* L.) and sapodilla (*Manikara achras* Fosberg). The fruit trees were aged 1-3 years. The vegetative residues around the study plot were used to cover the basin to reduce the moisture loss by soil water evaporation.

2. Design of rainwater-storage tank and installation

The amount of water harvested and water used by each fruit tree were calculated based on potential evapotranspiration (ETp) and actual evapotranspiration (ETa) of each fruit tree growing in the hedgerow during the dry season. Panomtaranichagul, & Nareubal (2007, p. 68) found that the water consumption of plant during January-April was not more than 3 mm/day. For this study, the plant water consumption for 1m^2 growing area was 3 mm/day or 3 L/day. Hence, water use by each fruit tree during the dry period (120 days) was equal to 360 liter or about 1,800 liter for each hedgerow with 5 fruit trees.

The rainwater-storage tanks were made of concrete casing pipe which were inexpensive and local availability. Two concrete cylinder tanks (0.95 m^3 capacity, 1x1.2 m each), 1.9 m^3 were used for each sub-plot with 5 fruit trees. The rainwater-storage tank were installed at the highest point of each selected sub-plot for which the water supplied to each fruit tree as drip irrigation was running down slope under gravitational force (Figure 1). In addition, a rainwater collecting plate with diameter of 1.4 m made from a zinc lid with a shape of a funnel having small holes in the middle part. These holes were made to filter foreign matters and to allow the rainwater flowing through the cement tank.

Figure 1 Rainwater harvesting cylindrical tanks and the overview of experimental plots.

3. Rainwater harvesting

Mae Chaem Watershed Research Station reported that the average annual rainfall in 2010 and 2011 at the experimental area was approximately 1,400 mm and 1,350 mm, respectively. Therefore, when the average rainfall was at least 1,000 mm, the rainwater harvested in rain collecting cylinder must be 1.54 m^3/tank (unlimited tank height), which was able to fulfill the storage tank (0.95 m^3 only) and was sufficient for all fruit trees consumption in each studied hedgerow. Rainwater was harvested during the rainy season (June-October), climatic data such as rainfall, air temperature, relative humidity, evaporation and amount of harvested water in the tanks were recorded.

4. Design of drip irrigation and installation

Design calculation based on engineering principle, were used to select the emitter, water pipelines and necessary equipments, which were low cost, effective and local availability. The design of drip irrigation system was started from the data collection such as the area, water source, soil, climate and plant. Then, the emitter was selected on the basis features such as the emitter type, flow rate, working pressure, quality and price. The next step was the plan design of pipe lines and system operation, and then the suitable pipe sizes and pressure losses of water flow within the pipelines were calculated by using Equation 1 (Kamchoo, 1992).

$$V = 1273\,Q / D^2 \qquad \text{....... (1)}$$

where V was velocity of water flow (m/s), Q was water flow rate (L/s), and D was inside diameter of pipe (mm), when the V was determined between 1.5-2 m/s, and the pressure head loss was computed by Hazen-Williams as Equation 2 (Keller, 1990).

$$H_f = 1.21 \times 10^{10} \cdot (Q / C)^{1.852} \cdot D^{-4.87} \cdot L \qquad \text{....... (2)}$$

where H_f = friction head loss (m), D = inside diameter (mm), L = pipe length (m), and C = coefficient of friction pipe, when the H_f of lateral line combined with sub-main line were determined to be not over than 20% of working pressure (Kamchoo, 1992). The calculation results were as follows.

(i) Emitter with flow rate adjustment valve of 0-120 L/hr and working pressure of 0.1-0.5 bar,
(ii) Lateral line, made of low density polyethylene (LDPE) plastic pipe with 16 mm diameter,
(iii) Main line, LDPE plastic pipe, 20 mm diameter and
(iv) Screen filter with 120 mesh opening.

Drip irrigation system was installed for each sub-plot. Filtration equipment and switch-control valve were connected to the water tank. Then, water pipes were installed from the water tank to the selected fruit trees. Emitters were installed at the tree planting pits (Figure 2a). Finally, drip irrigation system was tested to check the emitter working.

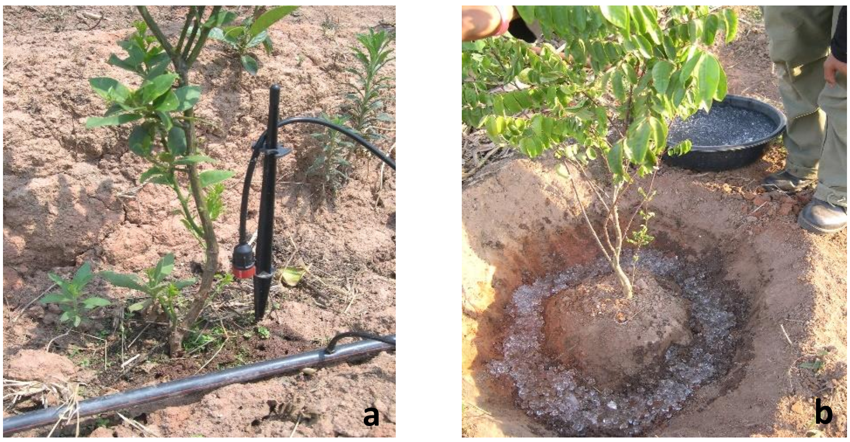

Figure 2 Installation of drip irrigation system (a) and polymer application (b)

5. Drip irrigation experiment

Drip irrigation experiment was carried out in the dry season during January-May of 2011-2012. The rate of water application for each fruit tree was calculated based on the actual evapotranspiration (ETa) for 1 m^2 growing area, which was 3 L/day or approximately 0.75 L/hr (12.5 ml/min) for 8 hr/day. The applied frequency was every 2 days interval of 120 days period. In addition, hydrophilic polymer was also applied to increase the water holding capacity within the root zone before drip irrigation experiment (Figure 2b). The furrow was dug around the fruit tree with 20-30 cm depth and 15-20 cm wide, 30 cm apart from the fruit trees. The saturated polymer mixed with the soil was poured into the furrow at the rate of 2 liters/tree (ThaiGreenAgro, 2010).

The experiment was designed as a Completely Randomized Design (CRD) with four replications of 4 irrigation practice-treatments, namely (i) non-irrigation (N), (ii) non-irrigation with polymer using (NP), (iii) drip irrigation (D), and (iv) drip irrigation with polymer using (DP). The effects of drip irrigation on total stored soil water, plant growing and some of soil properties were examined.

6. Measurement and data collection

6.1 Meteorological information

Meteorology information was collected from the weather station, Mae Chaem Watershed Research Station, Department of National Parks, Wildlife and Plant Conservation, Mae Chaem distrist, Chiang Mai province, which was approximately 1 km far from the experimental plot. The meteorological data such as rainfall, air temperature, relative humidity and wind speed were collected.

6.2 Soil water storages

Soil water content within 1 m depth, with every 20 cm depth increment-interval was measured by gravimetric method using a 1.2 m long soil sampling tube. The soil samples were taken periodically throughout the experimental period, to monitor the total stored soil water (TSW) within 1 m depth. The moisture content was determined as volumetric soil water content (θv, m^3/m^3), and TSW was calculated as equivalent depth (hw, mm).

6.3 Plant development (growth)

To evaluate the effects of dry-seasonal-drip irrigation on the hedgerow fruit tree development, the variables related to plant growth were measured such as plant height, plant canopy and trunk sizes. Measurement was conducted according to the plant growth periods. Water use efficiency of each fruit tree in the hedgerow was measured by the fruit tree development.

6.4 Soil properties

Soil samples within 0-40 cm depth were collected 3-4 times during the experimental period for measuring changes in some basic soil properties such as soil pH, organic matter (OM), bulk density (BD), particle density (PD), field capacity (FC), total porosity (TP), and aeration porosity (AP). Methods of soil property measurements and analysis were used according to the standard methods used in central laboratory of Soil Science Division, Department of Plant Science and Natural Resource, Faculty of Agriculture, Chiang Mai University.

Results and Discussion

Soil water storage

The results obtained from the 1st experiment (24 January-23 May 2011) showed that drip irrigation (D) and drip irrigation with polymer using (DP) gave the amounts of total stored soil water (approximately 40-50 mm) within 1 m depth higher than those given by non-irrigation (N and NP) (Figure 3). The available soil water within the root zone was increased substantially under drip irrigation treatment. The maximum soil water content under drip irrigation at the mid dry season (March) for D and DP methods were 343 and 352 mm, respectively. The highest soil water storage was carried out by the DP method. These were leading to well vegetative growth of the young fruit trees under sufficient available water with drip irrigation. Hydrophilic polymer application effected to soil water content before watering, which had drizzling, leading to the stored soil water decreased slightly. Therefore, the polymer application enhanced soil water storage if the water was added to the soil after using polymer. In addition, the minimum soil water storage in the non-irrigation method (N and NP) was in February, and some fruit trees without drip irrigation were withered.

The results obtained from the 2nd experiment (11 January-9 May 2012) showed that D and DP gave the amounts of total stored soil water (approximately 80-100 mm) within 1 m depth higher than those given by N and NP almost throughout the whole dry season (Figure 3). The maximum soil water content under drip irrigation at the mid dry season (April) for D and DP were 338 and 403 mm, respectively. The DP gave the stored soil water higher than D approximately 40-50 mm. The results showed that the polymer application increased irrigation efficiency; the stored soil water increased approximately 50%. Whilst, NP gave the stored soil water slightly higher than N, showing that polymer application without watering had no effect on soil water storage. Therefore, drip irrigation to the fruit tree hedgerow in the dry season combined with polymer application increased the water holding capacity within the root zone, increasing the irrigation efficiency. Furthermore, the minimum of soil water storage in non-irrigation (N and NP) which was in February, some fruit trees without drip irrigation were withered as well as in the 1st experiment.

The effects of drip irrigation and polymer application on the stored soil water in the 2nd experiment (2012) were different obviously than the 1st experiment (2011) due to rain in the middle and the end of experimental period in the 1st experiment. However, the results of these two experiments tended to be similar characteristics.

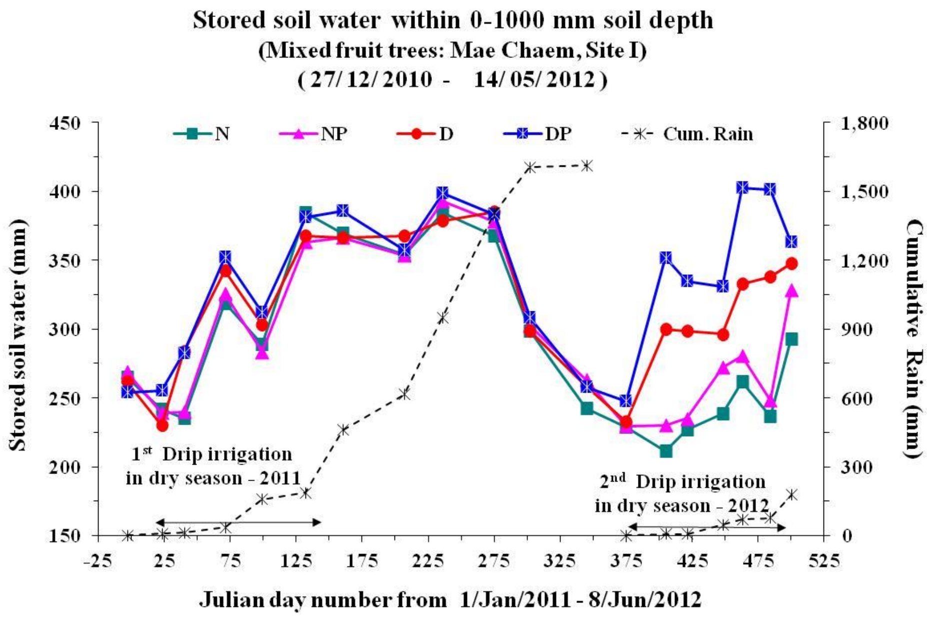

Figure 3 Total stored soil water within 0-1 m soil depth from December, 27th 2010 to May, 14th 2012

Plant growth

The results showed that the plant canopy and height of the fruit trees under drip irrigation were growing better than those without irrigation. Fruit tree growth under the N and NP methods were similar, and also the D and DP methods were also similar. Thus, considering only a comparison of the plant growth of fruit tree under N and D methods (Table 1). Analysis of variance showed plant growth was significantly different ($P < 0.05$) among irrigation. No significant differences were found among plants and also irrigation-plant interaction. Irrigated sapodilla dominantly increased in plant height more than in plant canopy, whilst irrigated mango and star apple responded to plant canopy more than plant height. However, lemon and guava responded to both plant height and canopy.

Table 1 Plant growth from December, 27th 2010 to May, 15th 2012

Plant	Plant Growth (%)					
	Non-irrigation			Drip irrigation		
	Height	Canopy	Mean	Height	Canopy	Mean
Mango	41.5	68.0	54.8a	57.2	116.3	86.8b
Lemon	59.0	43.8	51.4a	103.9	158.9	131.4b
Star apple	63.0	100.5	81.8a	77.9	162.5	120.2b
Guava	21.4	76.7	49.0a	58.0	149.3	103.7b
Sapodilla	12.4	52.4	32.4a	42.5	62.7	52.6b
Sig.		*			*	

Significant different at 0.05 α

In the 1st experiment, the 4 fruit trees without drip irrigation were died in the dry season (January-April), namely lemon, guava and sapodilla. The rate of plant growth of fruit trees without irrigation was slower, due to the halted growth during the dry season. Even though there were the rain in the middle and the end of experimental period. For the 2nd experiment, the 2 fruit trees without drip irrigation were died in the dry season, namely lemon and guava. In addition, the mean values of plant growth increment of mango, lemon, star apple, guava and sapodilla during December, 27th 2010 to May, 15th 2012 (505 days) under drip irrigation were higher than those under non-irrigation as 32, 80, 38, 55 and 20%, respectively (Figure 4).

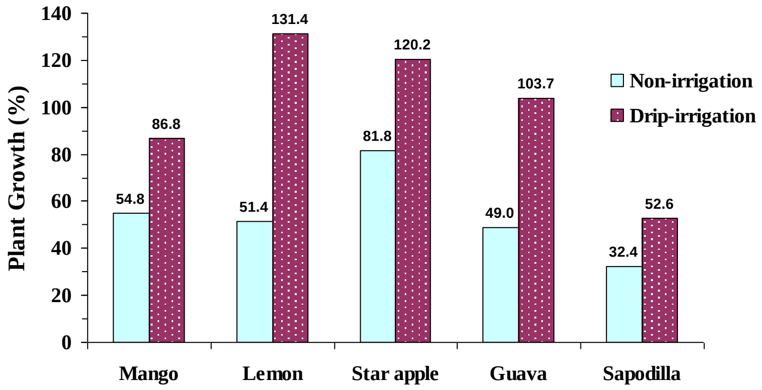

Figure 4 Plant growths during December, 27th 2010 to May, 15th 2012

Some soil properties such as soil pH, bulk density (BD), particle density (PD), field capacity (FC) and total porosity (TP) were not found a significant change. The results also found that organic matter (OM) and aeration porosity (AP) in the soil under drip irrigation tended to be better than without irrigation (Table 2). The soil moisture from drip irrigation in dry season was contributed to activities of small living and microorganism in soil increased. These showed that the drip irrigation was helped to increase soil fertility as well.

Table 2 Soil properties from December, 27th 2010 to May, 14th 2012

Soil properties	Non-irrigation (N)				Non-irrigation+Polymer (NP)				Drip irrigation (D)				Drip irrigation+Polymer (DP)			
	I = 27/12/2010; II = 12/5/2011; III = 10/1/2012; IV = 14/5/2012															
0-20 cm soil depth	I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II	III	IV
Bulk density (BD, gm/cm^3)	1.21	1.19	1.19	1.14	1.22	1.17	1.11	1.16	1.30	1.23	1.19	1.14	1.16	1.16	1.05	1.17
Particle density (PD, gm/cm^3)	2.43	2.60	2.44	2.42	2.46	2.44	2.47	2.38	2.44	2.47	2.46	2.40	2.45	2.43	2.49	2.43
Field capacity (FC, %)	36.13	36.56	38.73	39.92	36.31	39.14	40.00	36.85	34.56	37.73	38.39	38.34	39.01	40.25	40.52	37.60
Total porosity (TP, %)	50.13	53.93	51.08	52.91	50.69	52.21	54.79	51.33	47.12	50.11	51.27	52.70	52.39	52.26	57.75	51.82
Aeration porosity (AP, %)	14.00	17.37	12.35	12.99	14.39	13.09	14.71	14.48	12.56	12.38	12.88	14.36	13.38	12.01	17.23	14.22
Organic matter (OM, g/100g)	2.98	4.67	3.57	3.19	3.21	4.44	3.56	2.93	3.33	5.43	3.77	4.07	1.09	5.73	3.44	3.58
Soil acidity (pH)	4.82	5.05	4.81	4.16	4.15	4.58	4.77	4.19	4.47	4.83	4.78	5.32	4.53	4.67	4.78	5.01

Conclusion

This research aimed to increase conservative cultivation efficiency in the alley cropping system on sloping land by using the rainwater harvested and a drip irrigation system to provide water for the mixed fruit trees in the dry periods. To improve the hedgerow fruit productivity and soil fertility, to reduce the risk of fruit tree damage in dry season and to increase biological diversity of the fruit trees in alley cropping would be addressed. The results showed that drip irrigation gave substantially higher amount of stored soil water within 1 m soil depth than that of the non-irrigation. However, combination effect of drip irrigation and hydrophilic polymer tended to give the highest stored soil water throughout the experimental periods compared to either drip irrigation or non-irrigation. During the dry season, the stored soil water under drip irrigation was significantly increased whilst it was decreased under non-irrigation. Fruit trees without drip irrigation were withered and some were died. The results also showed that the plant canopy and height of fruit trees under drip irrigation were growing better than those without irrigation. Vegetative growth of mango, lemon, star apple, guava and sapodilla under drip irrigation were higher than those under non-irrigation at 32, 80, 38, 55 and 20%, respectively. Therefore, the drip irrigation for fruit trees during the dry season, using the rainwater harvested in the rainy season, could be the best strategy for decreasing fruit tree damage and increasing the growth rate successfully, leading to increased water use efficiency and productivity, quantity and quality of fruit production under rainfed condition. Particularly, this could enhance a sustainable alley cropping in highland rainfed agricultural system.

Acknowledgements

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