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# Evaluation of Soil Temperature, Water Productivity and Agronomic Performance of Potato (*Solanum Tuberosum* L.)-Legume Intercropping System in the Western Highlands of Cameroon

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**ABSTRACT:** Intercropping is a farming practice involving two or more crop species, growing simultaneously in the same area and which could efficiently utilize natural resources. A two-year study was conducted during 2021 and 2022 in the western highlands of Cameroon to examine the impacts of potato-legume intercropped on soil water content (SWC), productivity and soil temperature(ST) in order to identify cropping systems (CS) that controls ST and water productivity (WP). A randomised complete block design with seven treatments: sole potato crop (T1), *Mucuna* (T2), lima bean (T3), cowpea (T4) and intercropping systems of *Mucuna*+potato (T5), lima bean+potato (T6) and cowpea+potato (T7) was used. CS has a significant effect ($P<0.05$) on ST with the lowest ST being obtained in T5 (19.50°C), T7 (19.66°C) and T6 (19.68°C) against 20.20°C in T1. SWC varied with CS ($P<0.05$) with T1 having the lowest SWC of 40% versus T5 (47.90%), T6 (44.42%) and T7 (42.76%). Water use increased significantly ($P<0.05$) with T1 (783.34mm) and decreased from T7 (783.32mm) to T5 (783.30mm). As for WP, T1 (2.96g.mm$^{-1}$) recorded the lowest value and T5 (4.04g.mm$^{-1}$) the highest. T5 had the highest tuber yield (29.60t.ha$^{-1}$) and T1 the lowest (23.21t.ha$^{-1}$). Legume grain yield and biomass were highest in T5 (2.10t.ha$^{-1}$ and 6.78t.ha$^{-1}$ respectively) compared to others intercropping systems. The intercropping systems obtained an overall LER and WER greater than 1 with the highest in T6 (6.20 and 2.63). Intercropping potato with *Mucuna* or lima bean reduces soil temperature while improving soil water productivity that enhances potato production.

**KEYWORDS:** intercropping, soil temperature, water productivity, cover crop, *Solanum tuberosum*

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## INTRODUCTION

According to FAO (2011), potato production in Africa tripled from 1994 to 2011, from 8 to 24 million tons largely due to an increase in the area under cultivation. The same FAO data shows that total production in Africa, which was only 4% of global supply, increased to 9% ten years later. However, as the world's population and average income increased, so does the demand for food (Monfreda *et al*., 2008; Lobell *et al*., 2009). An estimated 50,000 to 65,000 hectares of land are cultivated for potato and it is ranked fifth in terms of produced tonnage in Cameroon (Foning *et al.*, 2014; Mengui *et al.*, 2019). It is grown extensively in 6 of the 10 regions, with the majority in the West and North West regions of Cameroon accounting for about 80% of the 435.4 tons of national production (Fontem *et al*., 2004).

Most of the potato yields are obtained during the rainy season and rain-fed agriculture is central to the food production process in Sub-Saharan Africa (Cooper *et al.*, 2008). The majority of farmers rely on rain-fed crop production systems and lack incentives to improve water use efficiency in agricultural production including the motivation to conserve water during the crop growing season (Abbate *et al.,* 2004; Steduto *et al.,* 2009). In rain-fed agricultural systems, soil water infiltration and storage in the root zone determines the overall availability and water use efficiency in crop production (Steduto *et al.*, 2009). Potato crop is mainly affected due to its superficial and fibrous root system, of which about 85% is concentrated in the upper 30 cm of the soil profile, making the crop very sensitive to drought (Reyes-Cabrera *et al*., 2016; Burke, 2017). Under water deficit conditions, potato leaves curl as a strategy to reduce transpiration rates, thereby reducing the intercepted radiation and resulting to a negative impact on water uptake (Struike *et al*., 1989). Optimum foliage growth and thus light interception in potato occurs at soil temperatures between 15 and 20°C (Rykaczewska, 2015). High soil temperature in the potato rhizosphere induces water stress that increases total dry matter allocation to roots and stems at the expense of tubers, thereby reducing crop water productivity (Thornton and Valente, 1996). Increasing night-time temperatures in the range of 0-20°C increases potato root length while increasing temperature above 25°C induces a sharp reduction in tuber number and weight (Davies *et al.*, 2002; Nyawade *et al.*, 2018). Nevertheless the adverse effects of high soil temperatures on potato growth can be optimized in cropping systems by incorporating legume cover crops capable of improving soil cover persistence and soil moisture content.

Intercropping is one such system that is well recommended due to its multiple benefits (Shimelis and Melis, 2014; Nyawade *et al.*, 2018, 2019; Gitari *et al.*, 2019;). Unfortunately little information is available on the soil temperature and crop water productivity in potato intercropping systems in relation to soil thermal regimes generated by associated crops. This information is necessary for the identification of management practices that can enhance the high soil temperature conditions that prevail in tropical and subtropical potato growing areas. Therefore, monitoring soil moisture content and soil temperature in potato-legume cover crop intercropping is important to lead to the best management practices for soil fertility and improve water use efficiency and soil temperature. Thus, this study sought to evaluate the influence of potato-legume cover crop intercropping on water productivity and soil temperature of different stages of growth and development of potato in the Western highlands of Cameroon.

## MATERIALS AND METHODS

### Presentation of the study area

A field trial on the potato-legume cover crop intercropping was conducted at the research and application farm of the University of Dschang located at latitude 5.45 and longitude 10.07. The city of Dschang is located in the Western highlands of Cameroon on the southwestern slope of the Bamboutos mountains and is dominated by a low plateau strongly dissected by small valleys sometimes swampy. The average annual rainfall varies between 1800 mm and 2000 mm. The average temperature is around 20° C with maximum ranging between 25 - 28° C in April and minimum ranging between 14-16° C in December (IRAD, 2002). The climate is characterized by a dry season from mid-November to mid-March and a rainy season from mid-March to mid-November. Soil was slightly acidic (table 1)

### Plant material

The potato cultivar 'Désirée' was used in this study. This cultivar is productive and it is a hybrid of "Urgenta" and "Depesche" breded in the Neitherlands. It has a production cycle between 70-90 days and is resistant to bacterial wilt and mildew. Its average tuber yield is between 25-30 $t.ha^{-1}$ (Tankou *et al.*, 2019).

The legume cover crops used in the study were, *Mucuna pruriens* cultivar utilis, lima bean (*Phaseolus lunatus* cultivar Sylvester Baudet) and cowpea (*Vigna unguiculuta* cultivar KEB-CP009).

### Experimental design and treatments

This study was laid out in a randomized complete block design with seven treatments, each representing a cropping system and four repetitions over an area of 752.4$m^2$, with 28 experimental units measuring 5m x 4.20m, resulting to a surface area of 21$m^2$. The experimental units were 0.5m apart and the blocks were 1m apart. The study was carried out during the cropping seasons of 2021 and 2022.

The experimental treatments were:

- T1: potato sole crop;
- T2: *Mucuna* sole crop;
- T3: lima bean sole crop;
- T4: cowpea sole crop;
- T5: potato-*Mucuna* intercropped;
- T6: potato-lima bean intercropped;
- T7: potato- cowpea intercropped.

### Agronomic practices

Field preparation consisting of cutting and removal of grasses and stumps, ploughing, laying out of blocks and experimental units took place in mid-February till early March of each year.

The different species were planted according to the 1:1 intercropping pattern (Tchapga *et al*., 2023), on March 15, 2021 for the first year and on March 8, 2022 for the second year with common planting distances of 40 x 80 cm. One potato tuber seed was planted per hole at a depth of 10 cm giving a planting density of 31250 $plants.ha^{-1}$(figure 1). For the three legumes cover crops, two seeds per hole giving a planting density of 62500 $plants.ha^{-1}$. The densities in intercropping were similar with those in monocropping for each specie.

The phytosanitary treatments against fungal diseases were carried out using Bonsoin (36% chlorothanil + 6% cymoxanil) on weekly basis to control late blight caused by *Phytophthora infestans* following the appearance of the first symptoms. An insecticidal treatment using parastar (20g.$L^{-1}$ Imidachloprid + 20g.$L^{-1}$ Lambdacyhalothrin) was conducted twice throughout the crop cycle. Mineral fertilization based on NPK (11-11-22) was done 30 days after sowing only on potato at the rate of 200kg.$ha^{-1}$.

**Data collection**

Soil water content (SWC) and temperature were determined on weekly basis during the long rainy season of 2021 and 2022 according to the potato growth and development stages (Hack *et al.*, 1993): stolon initiation (SI: 21-29 DAP), main stem elongation (MSE: 31-39 DAP), tuber formation (TF: 41-49 DAP), emergence of inflorescence (EI: 51-59 DAP), flowering coupled to tuber maturation (FcTM: 61-69 DAP) and fruit development coupled to tuber maturation (FDcTM: 71-79 DAP).

**Soil water content**

Soil water content was recorded by the gravimetric method. For each experimental unit, soil samples were collected to the depth of 0-20 cm according to the star sampling method using a soil auger. According to this method, samples were collected from 12 different locations at 12 different times in a 2 m x 2 m star area (figure 2) situated in the middle of the unit. After collection, the wet mass was assessed using a 0.01 decimal scale and then oven-dried at 105°C for 72h. After drying, the samples were weighed again and their dry mass noted. SWC was calculated according to Scott (2000):

SWC (%)=(wet soil mass - dry soil mass) X 100/wet soil mass .......................................(1)

**Soil temperature**

Soil temperature was assessed using an electronic soil tester (Abafia kit 4 in 1). This instrument is equipped with a 20 cm long probe with a sensor at its end and an electronic recorder that displays the soil temperature value in degrees Celsius. The determination consisted by introducing the probe to the depth of 20 cm and thereafter (2-3 minutes) recording the value of the soil temperature at three different spots on the experimental unit.

**Yield**

Six plants for potato and four plants for legume cover crop were selected and used for yield determination. At harvest (79 DAP), the total tuber yield per plant was weighed and the mean of the six plants per treatment was converted into t.$ha^{-1}$. The same evaluation was done for cowpea harvested at 120 DAP; Lima bean and *Mucuna pruriens* at 180 DAP.

**Assessment of water productivity**

SWC and precipitation data were used in the water balance equation for calculating water use (WU in mm) of the studied systems. Surface runoff did not occur because the experimental field was quite flat. Thus, the actual water use (WU) during the different growth periods was calculated using a simplified water balance equation according to Zhang *et al*. (2018):

WU= Pr + Sini - Send........…………………………………………………..............… (2)

where Pr (mm) is the precipitation in each period; Sini is the SWC (mm) in the top 0-20 cm soil layer (root zone) at the beginning of the period; Send is the soil water content at the end of the period. Water productivity (WP in g.$mm^{-1}$) was calculated as the ratio of the yield and the previously defined water use (Sadras *et al.*, 2011):

WP= Y/WU………………………………………………………………………………..(3)

where Y is crop yield (g) and WU is the actual water use per unit area of a system (mm).

**Land and water equivalent ratio**

Land equivalent ratio (LER) was used to assess land productivity at the system level in intercropping (Willey, 1979). The LER in intercropping was calculated using yield in intercropping and sole stands for each component crops according to Willey (1979):

$LER=LER_a + LER_b=Y_{int,a}/Y_{mono,a} + Y_{int,b}/Y_{mono,b}$…………………………………………..…(4)

where $Y_{int,a}$ and $Y_{int,b}$ are the yields of component crops a and b in the intercrop and $Y_{mono,a}$ and $Y_{mono,b}$ are yields of crops a and b in the monocultures. The $LER_a$ and $LER_b$ are partial LER (relative yield) for each species. The LER expresses the land area needed in sole crops to produce the same yields as a unit area of intercrop. LER of 1.0 indicates the same land productivity for intercropping and sole crops, while LER above 1.0 indicates an advantage in intercropping and less than 1.0 a disadvantage (Mead and Willey, 1980).

To assess the water use advantage of the intercropped system, the water equivalent ratio (WER) was defined by analogy to LER (Mao *et al*., 2012; Bai *et al*., 2016):

$WER=WER_a + WER_b = WP_{int,a}/WP_{mono,a} + WP_{int,b}/WP_{mono,b}$………………………………(5)

$WP_{mono,a}$ and $WP_{mono,b}$ are the water productivity of crop a and b in monocultures, $WP_{int,a}$ and $WP_{int,b}$ are the water productivity of component crop a and b in intercropping. WER > 1 indicates a water use advantage for the intercropped system, meaning that yields in the intercropped system are produced with less water than for the same yields in monoculture plots. Therefore, WER was used to determine whether water was used more efficiently in intercropping than in traditional sole cultivation (Mao *et al*., 2012).

If both LER > 1 and WER > 1, then the intercropped system requires less land and less water than monoculture cultivation.

**Data analysis**

The collected data were organized and subjected to one-way analysis of variance (ANOVA) and the mean of treatments were compared by Tukey's test at a probability threshold of 5% using Minitap version 19.1.0 software (Minitap Inc. CA. USA).

## RESULTS

**Weather conditions during the potato development stages from 2021 to 2022**

Ambient temperature increases from 20.81°C to 21.78°C during stolons initiation to fruit development coupled with tuber maturation respectively during the first year (Table 2). However, it decreased in the second year from 24.47°C during stolons initiation, to 22.57°C during fruit development coupled with tuber maturation. Rainfall fluctuated in the first year with a higher value during inflorescence emergence (315.9 mm) and a lower value during fruit development coupled with tuber maturation. In the second year, rainfall followed an ascending curve from 52.55 mm during stolons initiation to 198.85 mm during fruit development coupled with tuber maturation.

**Effect of potato-legume intercropping system on soil temperature**

Cropping system had a significant effect ($P<0.05$) on soil temperature and varied significantly with potato growth and developmental stages (Table 3). However, no significant variation ($P>0.05$) in soil temperature was observed during the two years of study. According to the developmental stage of potato, the soil temperature varied ($P<0.05$) only during the main stem elongation (MSE) and fruit development coupled with tuber maturation (FDcTM) in 2021 with a maximum value of 21.50°C in legume sole crop and potato-legume intercropping systems and a minimum of 21.13°C in potato sole crop (T1) during the main stem elongation. However, T1 (20.49°C) recorded the highest soil temperature during FDcTM followed by T5 (19.91°C), T7 (19.91°C) and T6 (19.74°C). The lowest value of soil temperature during FDcTM was recorded in T4 (19.41°C) equivalent to that of T3 (19.49°C) and T2 (19.58°C) (table 3). During 2022, the cropping system had a significant effect ($P<0.05$) on soil temperature only during FDcTM with the highest soil temperature in T1 (20.20°C) and the lowest in T2 (19.34°C) and T5 (19.50°C) followed by T7 (19.66°C) and T6 (19.68°C). In the first and second year of the study, soil temperature did not vary between cropping systems during the other stages of growth and development.

**Effects of potato-legume intercropping system on soil water content**

A significant variation ($P<0.05$) in soil water content was observed during the two years of study according to the cropping systems and potato growth and development stages (Table 4). Cropping system had a significant effect ($P<0.05$) on soil water content during TF and EI in the first year of study and from TF to FDcTM of the second year. However no significant effect of cropping system ($P>0.05$) was observed during SI, MSE, FcTM and FDcTM of the first year. In contrast to the first year, there was no significant ($P>0.05$) effect of cropping system during SI and MSE of the second year. Soil water content was highest during TF of the first year in T5 (37.55%) which was not significantly different to that obtained in T2 (31.05%), T4 (26.05%), T3 (24.40%), T6 (25.43%) and T7 (26.42%); with the lowest recorded in T1 (23.3%). However, a slight increase in soil water content was observed during EI of the same year with highest values in T4 (42.81%) and T3 (42.45%) being equivalent to that of T6 (41.92%), T7 (40.95%), T5 (40.30%) and T2 (38.71%); the lowest value was also recorded in T1 (34.16%). Soil water content during SI, MSE, FcTM and FDcTM of the first year of study was equivalent for all cropping systems.

Similarly, no variation in soil water content was observed during SI and MSE of the second year of study, but from TF to FDcTM. it was different from one cropping system to another; thus T4 (30.43%) recorded the highest value during TF equivalent to T7 (29.43%), T2 (29.29%), T6 (28.99%), T5 (28.90%) and T3 (27.34%). The lowest soil water content during this stage was observed in T1 (22.03%). A progressive increase in soil water content was recorded from EI to FDcTM with a higher value in T5 from 38.18% (EI), 47.12% (FcTM) to 47.90% (FDcTM) being statistically equivalent to T2, T4, T7, T6 and T3 during these stages of potato development. However, T1 recorded the lowest values of soil water content during these stages ranging from 26.88% (EI) to 40% (FDcTM).

**Effects of potato-legume intercropped on legume yield and biomass**

Cropping system had a significant effect ($P<0.05$) on legume grain yield and biomasses (Table 5). Similarly, only legume grain yield was significantly influenced ($P<0.05$) in both production years and interaction between cropping system and year. T5 (1.41t.ha$^{-1}$) had the highest legume grain yield in the first year of production which showed no statistical difference with the grain yield obtained in T7 (0.83t.ha$^{-1}$), T2 (0.74t.ha$^{-1}$) and T6 (0.73t.ha$^{-1}$). However, the smallest grain yields are recorded in T3 (0.49t.ha$^{-1}$) and T4 (0.68t.ha$^{-1}$). A significant increase in legume grain yield was recorded in the second year with the highest grain yield in T5 (2.10t.ha$^{-1}$) and T2 (1.83t.ha$^{-1}$) followed by T7 (1.01t.ha$^{-1}$), T6 (0.77t.ha$^{-1}$), T4 (0.75t.ha$^{-1}$) and T3 (0.52t.ha$^{-1}$). As for the legume biomass, T2 (5.31t.ha$^{-1}$) obtained the highest biomass in the first year being equivalent to T6 (4.60t.ha$^{-1}$), T3 (4.19t.ha$^{-1}$), T5 (3.94t.ha$^{-1}$) and T4 (3.38t.ha$^{-1}$). However, T7 (2.24t.ha$^{-1}$) recorded the lowest biomass. A non-significant increase was recorded in the second year for T5 (6.78t.ha), T2 (5.36t.ha$^{-1}$), T6 (4.65.ha$^{-1}$) and T7 (4.18t.ha$^{-1}$) showing no statistical difference between them. On the other hand, a non-significant decrease was obtained in T3 (3.30t.ha$^{-1}$) and T4 (3.33t.ha$^{-1}$) presenting the smallest biomasses equivalent between them.

**Effects of potato-legume intercropped on potato yield**

The cropping system did not have a significant effect (P>0.05) on potato tuber yield in the first year of the trial in contrast to the second year where a significant effect (P<0.05) was recorded (Table 6) with T5 (29.60t.ha$^{-1}$) having the largest tuber yield statistically equivalent to T6 (26.72t.ha$^{-1}$). On the other hand, T7 (24.90t.ha$^{-1}$) and T1 (23.21t.ha$^{-1}$) had the smallest tuber yields. However, no significant variation in tuber yield was observed over the years.

**Water productivity on potato-legume intercropped over year**

WU was significantly (P<0.05) influenced by cropping system and varied significantly across years (P<0.05). However, the interaction of cropping system and year showed no significant (P>0.05) effect on WU (Table 7). To this effect, a variation in WU was observed only during 2022 with T1 (783.34mm) having used the highest amount of water and the lowest amounts were recorded in T4 (783.30mm), T2 (783.30mm) and T5 (783.30mm).

Regarding WP, the cropping system had a significant effect (P<0.05) and a non-significant variation (P<0.05) was observed during the two years of study. As a result, the WP was high in T6 (3.77g.mm$^{-1}$) showing no statistical difference to T1 (3.62g.mm$^{-1}$), T5 (3.40g.mm$^{-1}$) and T7 (3.30g.mm$^{-1}$) during 2021. In the second year of the study, WP was high in the intercropping systems with its highest value in T5 (4.40g.mm$^{-1}$) statistically equivalent to T6 (3.51g.mm$^{-1}$) and T7 (3.30g.mm$^{-1}$) then followed by T1 (2.96g.mm$^{-1}$). However, pure legume crops recorded the lowest values of WP.

**Land and water equivalent ratio of potato-legume intercropped over year**

Total and partial LER varied significantly (P<0.05) according to the cropping system but no significant variation (P>0.05) was observed in the two years of study (Table 8). The partial and total LER in both years were greater than 1 with a total LER of 6.04 and 6.20 obtained in T6 in the first and second year of the study respectively. These values showed no statistical difference from those obtained in T5 (3.29 and 3.01) and T7 (3.10 and 2.76).

Cropping system had a significant effect (P<0.05) on total WER that did not vary significantly (P>0.05) with year (Table 9). Total WER was greater than 1 for all intercropping systems with its greatest value in T5 (3.05) and T6 (2.63) in the first and second year respectively.

## DISCUSSION

**Effect of potato-legume intercropped on soil temperature**

The cropping system influences significantly (P<0.05) the soil temperature (Table 3) with a variation during main stem elongation (MSE) and fruit development coupled with tuber maturation (FDcTM). This variation in soil temperature with potato developmental stages, could be due to the fact that heat transfer in the soil and latent heat exchange at the surface are the main causes of soil temperature variations (Hu *et al*.. 2019; Nwankwo and Ogagarue. 2012) which is observable, with the decrease in mean ambient temperature with potato developmental stages. The high temperatures recorded in pure legume cropping systems and intercropping system during the elongation of the main stem of potato, could be explained by the fact that these systems at the beginning of the growth phase, do not have a consequent biomass to reduce the impact of ambient temperature on the soil surface taking into consideration that soil temperature is a function of the heat flux in the soil as well as the heat exchange between the soil and the atmosphere (Elias *et al*.. 2004). However, a clear decrease in soil temperature during fruit development coupled with tuber maturation in intercropping systems and pure legume cover crops sufficiently showed the impact of the high biomass produced at this stage on soil temperature. To this, cover crops can alter soil temperatures through the high density of the canopy produced relative to bare soil, which in turn can impact both crop productivity and global warming (Lombardozzi *et al*.. 2018).

**Effect of potato-legume intercropped on soil water content**

Soil water content varied significantly with development stage and cropping system (Table 4), with a variation from TF to EI in the first year and from TF to FDcMT in the second year. The pure legume cover crop systems and the intercropping systems presented higher values of soil water content compared to the potato sole crop. To this effect, the *Mucuna* sole and potato-*Mucuna* intercropped presented the highest soil water content which could be justified by the fact that, the soil cover by its cover crops at these stages of development largely contributed to the conservation of the soil water content both in their pure cultivation and in intercropping unlike the potato sole crop. In addition, the high biomass of *Mucuna* in pure culture as well as in intercropping favored a better conservation of the water content contrary to the lima bean and the cowpea. These results are in agreement with those of Sainju and Sing (1997) and Janeth *et al*. (2014) who observed a significant contribution of lablab and vetch on soil moisture conservation and increase in soil productivity compared to the pure maize cropping system, respectively. Similarly, the findings of Dahmardeh and Rigi (2013) confirm that soil moisture content is significantly higher in the maize-legume intercropping than in the monocropping, due to the high evaporation potential of maize.

**Effect of potato-legume intercropped on WU and WP**

Water use and water productivity were significantly influenced (Table 7) by cropping system and varied significantly from year to year. In the first year of the study, water use (WU) distributed equally among the cropping systems and increased significantly in the second year with more water used in pure potato than in legume sole crop and intercropping systems. To this, potato in monocropping consumed more soil water than legume sole crop and intercropping systems due to slower early growth of potato and relatively small canopy that did not cover the soil in time, resulting in high soil evaporation (Xie *et al.*, 2012), thus increasing water consumption and decreasing water productivity observed in potato sole crop. Similarly, the *Mucuna*+potato intercropped with its high biomass production would have significantly reduced evaporative water losses (which is the main component of evapotranspiration that contributes to the higher water consumption of the farming systems) resulting in higher water productivity in contrast to other intercropping system and potato sole crop. These results agree with Ren *et al.* (2018) that the potato-vetch intercropping system had high water productivity compared to the potato monocropping. The mechanism leading to the elevation of water productivity of the *Mucuna*+potato intercropping system could be due to the reduction of soil evaporation at an early stage due to the increase in soil cover in this intercropping system, as also found in the maize-pea intercropping (Mao *et al.*, 2012); the complementary distribution of the roots of the components crops efficiently filling the available soil volume as the root system of potato is mainly distributed in the 0-40 cm soil layer (El-Abedin *et al.*, 2017) and finally the difference in spatial-temporal water requirements of each species in the intercropping system (Bai *et al*., 2016). In addition, the elevation in water productivity would also be attributed to the increase in potato tuber yield in intercropping system. These results corroborate those of Ahmed and Mahmoud (2015) who showed that the water productivity values of the maize-soybean intercropping system were higher than those obtained from the pure maize and soybean crops in two growing seasons and under irrigation and attributed these results to the increased of grain yield of the intercropping system compared to the grain yield of the pure maize and soybean crops.

**Effect of potato-legume intercropped on potato yield, legume yield and biomass**

A non-significant increase in potato yield was observed in both year of the study with a significant variation in the second year marked by the *Mucuna*-potato intercropping giving the highest tuber yield followed by the lima bean-potato intercropping compared to the potato sole crop (Table 6). This could be due to the return of nutrients to the soil by the high biomass produced by the *Mucuna* and lima bean. Similarly, it was reported that when *Mucuna* biomasses were incorporated into the soil, the application of a minimal dose of fertilizer had greater effects on crop yield than when *Mucuna* was only incorporated into the soil (Ngome *et al*., 2012). This suggests that *Mucuna* and fertilizer application could complement each other to improve soil fertility and increase crop yields. In addition, the increase in potato yields in intercropping, could be explained by better water use of potato in intercropping with *Mucuna* and lima bean whose total soil cover limited evaporation, soil temperature and reduced water stress (Ogindo and Walker, 2005; Borowy, 2012). It is noted that potato is very sensitive to water stress during tuber development (Hill *et al*., 2021). Sharaiha and Hadidi (2008) and Rezig *et al.* (2013) observed higher productivity when potato was grown in intercropping with beans and sulla (*Hedysarum coronarium* L.) respectively, compared to potato sole crop.

*Mucuna*, both in intercropping and in sole crop obtained the highest grain yield and biomass compared to the other cover crops (Table 5). This could be due to the fact that *Mucuna* has no specific rhizobium requirements and therefore can fixed more nitrogen than cowpea and lima bean contributing to increased atmospheric nitrogen uptake serving to improve its growth and yield (Dogbe *et al*., 2002; FAO, 2011). According to Buckles *et al.* (1998), *Mucuna* yields reliably under dry farming and low fertility conditions that would not allow the profitable cultivation of most other food legumes.

**Effect of potato-legume intercropped on LER and WER**

Cropping system significantly influences LER and WER although they do not vary significantly over the two years of study (Table 8 and 9). All cropping systems had average LER and WER greater than 1 indicating that soil and water use efficiency were higher in the potato+ legume cover crop intercropping than in the pure potato crop. This being an advantage of the intercropping system over the pure cropping system. These results confirm those of Bai *et al.*(2016). Similarly, the findings of Valdez *et al*. (1988) and Mahapatra (2011) confirmed that the advantages of intercropping in crop production over monocropping are due to the interaction between the components of the associated crops and the difference in competition for environmental resource use. This implies that increasing land use efficiency could improve environmental quality by improving soil water and crop quality.

## CONCLUSION

The intercropping highlighted in this study could be a viable option to improve potato yield. The intercropping between potato and legume cover crops could significantly increase soil water content at the expense of increasing soil temperatures. The tested intercrop combinations also improve overall water and land productivity with the *Mucuna*-potato and lima bean-potato intercropping showing the best performance. By improving land and water productivity, these intercropping systems can potentially increase the sustainability of the potato cropping system. Therefore, for maximum potato production, farmers should practice an intercropping of potato with *Mucuna* or lima bean.

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**TABLES**

**Table 1**: Initial soil physico-chemical properties

| Soil parameters | Sand(%) | Loam(%) | Clay(%) | $pH_{water}$ | mo (%) | N(%) | C/N | K (mmol $100g^{-1}$) | CEC (mmol $100g^{-1}$) | P ($mgkg^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| Results | 65.0 | 22.0 | 14.0 | 6.4 | 14.37 | 0.269 | 32.28 | 3.20 | 45.33 | 16.11 |

**Table 2: ambient temperature and rainfall during potato growth and development stages during 2021 to 2022**

| Potato growth and development stages | Climatic data | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Cropping season 2021 | | | | Cropping season 2022 | | | |
| | Tmin | Tmax | Tmean | Rainfall | Tmin | Tmax | Tmean | Rainfall |
| SI | 14.84 | 26.78 | 20.81 | 117.31 | 19 | 29.95 | 24.47 | 52.55 |
| MSE | 15.93 | 27.25 | 21.59 | 40.35 | 19.61 | 27.56 | 23.58 | 84.77 |
| TF | 15.66 | 27.49 | 21.58 | 128.74 | 19.67 | 27.5 | 23.58 | 144.37 |
| EI | 15.28 | 26.46 | 20.87 | 315.9 | 19.65 | 26.51 | 23.08 | 132.89 |
| FcTM | 16 | 27.64 | 21.82 | 66.39 | 20.08 | 26.96 | 23.52 | 169.97 |
| FDcTM | 16.6 | 26.97 | 21.78 | 37.34 | 19.17 | 25.98 | 22.57 | 198.85 |

SI= stolon initiation, MSE=main stem elongation, TF=tuber formation, EI=emergence of inflorescence, FcTM=flowering coupled to tuber maturation, FDcTM=fruit development coupled to tuber maturation.

**Table 3: Effect of potato-legume intercropped on soil temperature at different growth and developmental stages in 2021 and 2022 cropping seasons**

| **Cropping system** | **Température (°C)** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | | | | | | 2022 | | | | | |
| | (SI) 21-29DAP | (MSE) 31-39DAP | (TF) 41-49DAP | (EI) 51-59DAP | (FcTM) 60-69DAP | (FDcTM) 70-79DAP | (SI) 21-29DAP | (MSE) 31-39DAP | (TF) 41-49DAP | (EI) 51-59DAP | (FcTM) 60-69DAP | (FDcTM) 70-79DAP |
| T1 | 21.75±0.50a | 21.13±0.25b | 20.91±0.17a | 21.06±0.32a | 20.25±0.50a | 20.49±0.43a | 21.87±0.62a | 21.62±0.75a | 21.22±0.86a | 20.45±0.40a | 20.12±0.25a | 20.20±0.24a |
| T2 | 21.75±0.50a | 21.50±0.00a | 21.50±01a | 20.81±0.45a | 20±00a | 19.58±0.50b | 21.87±0.25a | 21.25±0.50a | 20.71±0.90a | 20.05±0.55a | 19.73±0.30a | 19.34±0.10b |
| T3 | 21.75±0.96a | 21.50±0.00a | 21.41±0.49a | 20.75±0.46a | 20±00a | 19.49±0.43b | 21.63±0.87a | 22.12±0.85a | 21.34±0.77a | 20.37±0.87a | 19.99±0.00a | 19.71±0.23ab |
| T4 | 21.50±0.57a | 21.50±0.00a | 21.74±0.56a | 20.93±0.49a | 19.99±0.27a | 19.41±0.49b | 21.62±0.75a | 21.50±0.70a | 21.25±0.95a | 20.43±0.41a | 19.94±0.23a | 19.82±0.26ab |
| T5 | 22.00±0.81a | 21.50±0.00a | 21.24±0.49a | 20.93±0.62a | 20.08±0.16a | 19.91±0.17ab | 21.62±0.75a | 21.62±1.10a | 21.12±1.10a | 20.31±0.59a | 19.62±0.47a | 19.50±0.40b |
| T6 | 22.25±0.50a | 21.50±0.00a | 21.83±0.88a | 21.25±0.92a | 19.91±0.17a | 19.74±0.32ab | 22.50±0.40a | 22.25±0.95a | 21.75±1.32a | 20.69±1.02a | 19.99±0.09a | 19.68±0.28ab |
| T7 | 21.75±0.50a | 21.50±0.00a | 21.24±0.57a | 20.87±0.35a | 19.91±0.17a | 19.91±0.17ab | 22.37±0.75a | 22.62±0.47a | 21.35±0.77a | 20.44±0.72a | 19.79±0.33a | 19.66±0.34ab |
| P-value | 0.770 | 0.000 | 0.484 | 0.628 | 0.505 | 0.012 | 0.337 | 0.226 | 0.871 | 0.718 | 0.204 | 0.011 |

| Summary of analysis of variance | | | | | | |
|---|---|---|---|---|---|---|
| | CS | PDS | YEAR | CSxPDS | CSxYear | PDSxYear |
| Df | 6 | 5 | 1 | 30 | 6 | 5 |
| F-value | 2.38 | 103.76 | 1.03 | 1.39 | 1.20 | 4.55 |
| P-value | 0.041 | 0.000 | 0.315 | 0.741 | 0.320 | 0.002 |

Means that do not share a letter in the same column are significantly different at 5% probability threshold. DAP= day after planting; T1=potato sole crop; T2=*Mucuna* sole crop; T3= lima bean sole crop; T4= cowpea sole crop; T5=potato + *Mucuna*; T6=potato + lima bean; T7=potato + cowpea; Df=degree of freedom; PDS=potato growth and development stages; CS=cropping system; SI= stolon initiation; MSE=main stem elongation; TF=tuber formation; EI=emergence of inflorescence; FcTM=flowering coupled to tuber maturation; FDcTM=fruit development coupled to tuber maturation.

**Table 4: Soil water content as influenced by potato-legume intercropped at different growth and developmental stages in 2021 and 2022 cropping seasons**

| Cropping system | Soil water content (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2021 | | | | | | 2022 | | | | | |
| | (SI) 21-29DAP | (MSE) 31-39DAP | (TF) 41-49DAP | (EI) 51-59DAP | (FcTM) 60-69DAP | (FDcTM) 70-79DAP | (SI) 21-29DAP | (MSE) 31-39DAP | (TF) 41-49DAP | (EI) 51-59DAP | (FcTM) 60-69DAP | (FDcTM) 70-79DAP |
| T1 | 33.92±1.15a | 36.40±0.37a | 23.3±1.19b | 34.16±4.11b | 32.80±7.82a | 34.80±7.82a | 26.04±2.78a | 23.44±2.14a | 22.03±1.40b | 26.88±2.26b | 38.75±2.99b | 40.00±3.56b |
| T2 | 33.62±0.95a | 35.17±4.74a | 31.05±8.90ab | 38.71±6.41ab | 35.85±5.69a | 37.35±5.73a | 23.48±2.23a | 25.87±1.22a | 29.29±1.37a | 37.63±5.74a | 45.75±1.89ab | 47.16±1.47ab |
| T3 | 34.05±2.52a | 36.40±2.01a | 24.40±3.21ab | 42.45±5.95a | 37.2±1.97a | 39.2±1.97a | 24.04±4.39a | 22.50±2.75a | 27.34±1.27a | 32.51±3.91ab | 41.33±1.62ab | 42.86±2.00ab |
| T4 | 32.62±1.50a | 39.77±3.33a | 26.05±2.91ab | 42.81±3.73a | 40.42±3.59a | 42.42±3.59a | 21.11±1.73a | 24.60±1.95a | 30.43±1.94a | 36.42±5.69a | 44.02±3.02ab | 44.75±2.22ab |
| T5 | 33.42±1.62a | 39.40±1.15a | 37.55±10.93a | 40.30±3.80ab | 35.15±5.69a | 37.15±5.69a | 24.66±3.17a | 24.36±3.99a | 28.90±2.05a | 38.18±7.46a | 47.12±1.72a | 47.90±1.34a |
| T6 | 35.12±1.36a | 37.15±1.74a | 25.43±3.92ab | 41.92±7.69ab | 34.17±7.36a | 36.18±7.36a | 23.86±1.78a | 20.90±2.38a | 28.99±1.97a | 35.65±5.41a | 42.66±3.96ab | 44.42±3.41ab |
| T7 | 33.64±1.68a | 37±1.32a | 26.42±3.93ab | 40.95±3.53ab | 36.08±6.23a | 38.07±6.23a | 23.03±3.05a | 21.18±1.89a | 29.43±4.0a | 35.51±7.17ab | 42.44±6.49ab | 42.76±6.20ab |
| P-value | 0.531 | 0.151 | 0.038 | 0.028 | 0.653 | 0.650 | 0.389 | 0.081 | 0.000 | 0.003 | 0.051 | 0.040 |

| Summary of analysis of variance | | | | | | |
|---|---|---|---|---|---|---|
| | CS | PDS | YEAR | CSxPDS | CSxYear | PDSxYear |
| Df | 6 | 5 | 1 | 30 | 6 | 5 |

| | | | | | | |
|---|---|---|---|---|---|---|
| F-value | 4.25 | 55.85 | 18.39 | 0.84 | 0.55 | 31.72 |
| P-value | 0.001 | 0.000 | 0.000 | 0.692 | 0.770 | 0.000 |

Means that do not share a letter in the same column are significantly different at 5% probability threshold. DAP= day after planting; T1=potato sole crop; T2=*Mucuna* sole crop; T3= lima bean sole crop; T4= cowpea sole crop; T5=potato + *Mucuna*; T6=potato + lima bean; T7=potato + cowpea; Df=degree of freedom; PDS=potato growth and development stages; CS=cropping system; SI= stolon initiation; MSE=main stem elongation; TF=tuber formation; EI=emergence of inflorescence; FcTM=flowering coupled to tuber maturation; FDcTM=fruit development coupled to tuber maturation.

**Table 5: Effects of potato-legume intercropped on legume yield and biomass**

| Cropping system | Grain yield (t.ha$^{-1}$) | | Biomass (t.ha$^{-1}$) | | | |
|---|---|---|---|---|---|---|
| | 2021 | 2022 | 2021 | 2022 | | |
| T2 | 0.74±0.43ab | 1.83±1.23ab | 5.31±3.36a | 5.36±3.59ab | | |
| T3 | 0.49±0.48b | 0.52±0.52c | 4.19±2.95ab | 3.30±1.72b | | |
| T4 | 0.68±0.56b | 0.75±0.30c | 3.38±2.14ab | 3.33±1.87b | | |
| T5 | 1.41±0.88a | 2.10±1.30a | 3.94±2.49ab | 6.78±4.58a | | |
| T6 | 0.73±0.89ab | 0.77±0.88c | 4.60±2.97ab | 4.65±3.33ab | | |
| T7 | 0.83±0.74ab | 1.01±0.50bc | 2.24±1.42b | 4.18±2.79ab | | |
| P-value | 0.009 | 0.000 | 0.032 | 0.006 | | |
| Summary of analysis of variance | | | | | | |
| | CS | | Year | | CSxYear | |
| | Grain yield | Biomass | Grain yield | Biomass | Grain yield | Biomass |
| DF | 5 | 5 | 1 | 1 | 5 | 5 |
| F-value | 12.41 | 3.29 | 11.07 | 1.47 | 2.87 | 2.00 |
| P-value | 0.000 | 0.008 | 0.001 | 0.228 | 0.017 | 0.083 |

Means that do not share a letter in the same column are significantly different at 5% probability threshold. T1=potato sole crop; T2=*Mucuna* sole crop; T3= lima bean sole crop; T4= cowpea sole crop; T5=potato + *Mucuna*; T6=potato + lima bean; T7=potato + cowpea; Df=degree of freedom, CS=cropping system.

**Table 6: effect of potato-legume intercropped on potato yield over year**

| Cropping system | Potato yield (t.ha$^{-1}$) | | |
|---|---|---|---|
| | 2021 | 2022 | |
| T1 | 25.60±11.67a | 23.21±74.47b | |
| T5 | 22.64±13.13a | 29.60±46.22a | |
| T6 | 25.90±10.49a | 26.72±65.44ab | |
| T7 | 22.49±12.72a | 24.90±52.78b | |
| P-value | 0.643 | 0.003 | |
| Summary of analysis of variance | | | |
| | CS | Year | CSxYear |
| DF | 3 | 1 | 3 |
| F-value | 0.92 | 2.13 | 2.11 |
| P-value | 0.431 | 0.146 | 0.100 |

Means that do not share a letter in the same column are significantly different at 5% probability threshold. T1=potato sole crop; T2=*Mucuna* sole crop; T3= lima bean sole crop; T4= cowpea sole crop; T5=potato + *Mucuna*; T6=potato + lima bean; T7=potato + cowpea; Df=degree of freedom; CS=cropping system.

**Table 7: Effect of potato-legume intercropping on WU and WP**

| Cropping system | WU (mm) | | | WP ($g.mm^{-1}$) | | |
|---|---|---|---|---|---|---|
| | 2021 | | 2022 | 2021 | | 2022 |
| T1 | 706.02±0.02a | | 783.34±0.01a | 3.62±0.38a | | 2.96±0.47b |
| T2 | 706.01±0.02a | | 783.30±0.01b | 0.10±0.03b | | 0.23±0.05c |
| T3 | 706.01±0.01a | | 783.32±0.01ab | 0.70±0.04b | | 0.06±0.03c |
| T4 | 705.99±0.01a | | 783.30±0.01b | 0.10±0.05b | | 0.09±0.02c |
| T5 | 706.01±0.01a | | 783.30±0.01b | 3.40±0.83a | | 4.04±0.52a |
| T6 | 706.02±0.03a | | 783.31±0.01ab | 3.77±0.56a | | 3.51±0.46ab |
| T7 | 706.01±0.02a | | 783.32±0.02ab | 3.30±1.13a | | 3.30±0.34ab |
| P-value | 0.469 | | 0.010 | 0.000 | | 0.000 |
| Summary of analysis of variance | | | | | | |
| | CS | Year | CS x Year | CS | Year | CS x Year |
| DF | 6 | 1 | 6 | 6 | 1 | 6 |
| F-value | 2.73 | $2.17^{E}08$ | 0.81 | 111.74 | 0.03 | 1.31 |
| P-value | 0.025 | 0.000 | 0.569 | 0.000 | 0.866 | 0.272 |

Means that do not share a letter in the same column are significantly different at 5% probability threshold. T1=potato sole crop; T2=*Mucuna* sole crop; T3= lima bean sole crop; T4= cowpea sole crop; T5=potato + *Mucuna*; T6=potato + lima bean; T7=potato + cowpea; Df=degree of freedom; WU=water use; WP=water productivity, CS=cropping system.

**Table 8: Effect of potato-legume on LER**

| Cropping system | LER | | | | | |
|---|---|---|---|---|---|---|
| | 2021 | | | 2022 | | |
| | $LER_p$ | $LER_l$ | LER | $LER_p$ | $LER_l$ | LER |
| T1 | 1a | / | 1b | 1b | / | 1b |
| T2 | / | 1a | / | / | 1a | / |
| T3 | / | 1a | / | / | 1a | / |
| T4 | / | 1a | / | / | 1a | / |
| T5 | 1.01±0.48a | 2.27±0.88a | 3.29±1.08ab | 1.40±0.12a | 1.61±0.78a | 3.01±0.71ab |
| T6 | 1.12±0.27a | 4.92±4.80a | 6.04±4.80a | 1.29±0.20a | 4.91±4.79a | 6.20±4.71a |
| T7 | 1.01±0.54a | 2.08±1.55a | 3.10±1.72ab | 1.19±0.13ab | 1.57±0.24a | 2.76±0.27ab |
| P | 0.997 | 0.081 | 0.010 | 0.000 | 0.061 | 0.004 |
| Summary of analysis of variance | | | | | | |
| | CS | | Year | | CSxYear | |
| Df | 6 | | 1 | | 6 | |
| F-value | 8.39 | | 0.02 | | 0.02 | |
| P-value | 0.000 | | 0.899 | | 1.000 | |

Means that do not share a letter in the same column are significantly different at 5% confidence interval. T1=potato sole crop; T2=*Mucuna* sole crop; T3= lima bean sole crop; T4= cowpea sole crop; T5=potato + *Mucuna*; T6=potato + lima bean; T7=potato + cowpea; Df=degree of freedom, CS=cropping system, $LER_{p,l}$=partial LER of potato and legume.

**Table 9: Effect of potato-legume on WER**

| Cropping system | WER | | | | | |
|---|---|---|---|---|---|---|
| | 2021 | | | 2022 | | |
| | $WER_p$ | $WER_l$ | WER | $WER_p$ | $WER_l$ | WER |
| T1 | 1a | / | 1b | 1c | / | 1b |
| T2 | / | 1a | / | / | 1a | / |
| T3 | / | 1a | / | / | 1a | / |
| T4 | / | 1a | / | / | 1a | / |
| T5 | 0.88±0.21a | 2.16±1.24a | 3.05±1.29a | 1.28±0.08a | 1.09±0.40a | 2.37±0.32a |
| T6 | 1.01±0.14a | 1.58±0.81a | 2.59±0.91ab | 1.16±0.12ab | 1.47±0.82a | 2.63±0.74a |
| T7 | 0.88±0.29a | 1.70±1.38a | 2.59±1.52ab | 1.08±0.07bc | 1.36±0.24a | 2.44±0.25a |
| P | 0.708 | 0.225 | 0.002 | 0.000 | 0.317 | 0.000 |
| Summary of analysis of variance | | | | | | |
| | CS | | Year | | CSxYear | |
| Df | 6 | | 1 | | 6 | |
| F-value | 14.14 | | 0.44 | | 0.33 | |
| P-value | 0.000 | | 0.511 | | 0.919 | |

Means that do not share a letter in the same column are significantly different at 5% probability threshold. T1=potato sole crop; T2=*Mucuna* sole crop; T3= lima bean sole crop; T4= cowpea sole crop; T5=potato + *Mucuna*; T6=potato + lima bean; T7=potato + cowpea; Df=degree of freedom, $WER_{p,l}$=partial WER of potato and legume. CS=cropping system.

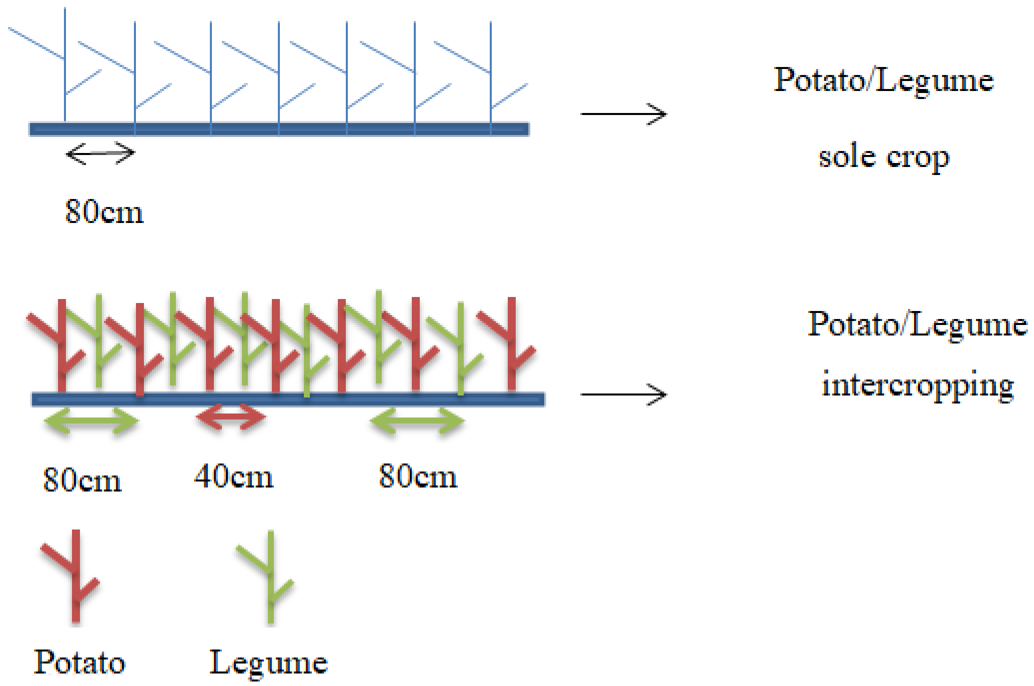


**Figure 1: Plant pattern diagram**

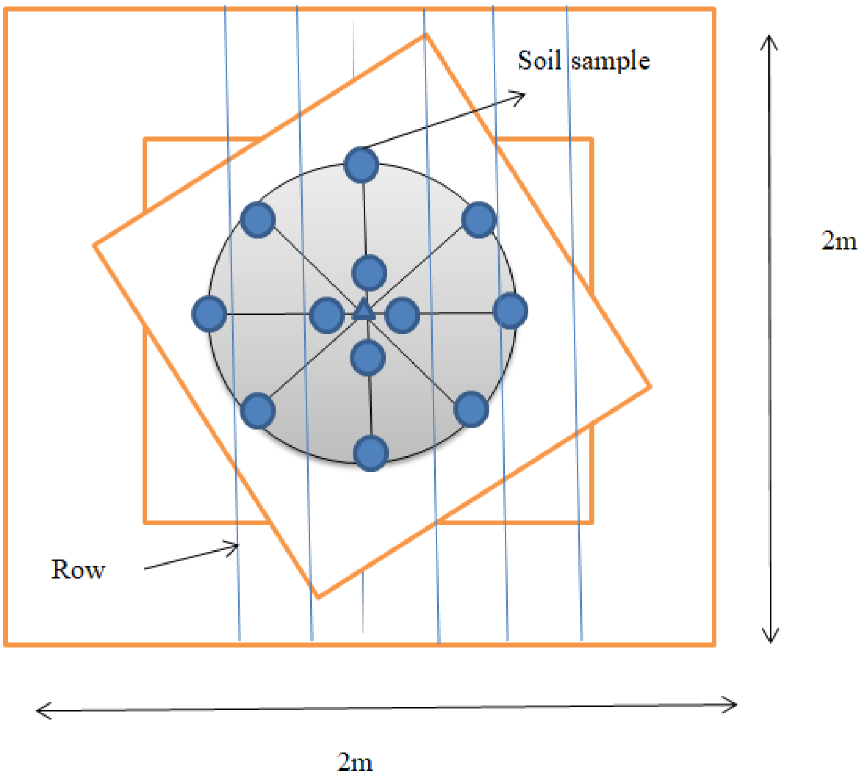


**Figure 2: star sampling method**