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# Sustainability strategies and soil fertility in the dryland Bình Thuân, Vietnam

*Estrategias sostenibles y fertilidad del suelo en la zona árida de Bình Thuân, Vietnam*
*Estratégias sustentáveis e fertilidade do solo na zona árida de Bình Thuân, Vietname*

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## ABSTRACT

Land degradation caused by both human impact and climatic factors leads to desertification and results in a reduction of the vegetation cover, erosion and a loss of soil fertility followed by socioeconomic problems. In particular, non-adjusted land use practices are the main driving forces for desertification. The present study examines how sustainability strategies under dragon fruit and peanut cultivation in Bình Thuân, Vietnam, influence soil fertility in a region that is characterised by Arenosols and a semi-arid climate. The coastal area is prone to desertification which complicates agricultural production. For that purpose, soil analyses for various soil parameters were combined with a socio-scientific survey based on the evaluation of quantitative interviews and a SWOT analysis. The results indicate that no significant effects of sustainability strategies on soil fertility could be measured. Furthermore, no evidence was found that intercropping enhances soil fertility, since soil parameters were not higher under dragon fruit intercropped with peanut than under monoculture. A higher nutrient concentration directly next to the dragon fruit shows that dragon fruit cultivation contributes more to soil fertility than peanut cultivation. This is especially because of the application of mulch around the plant which increases the humus content in soil and keeps the nutrients from leaching. However, the non-cultivated area in between the dragon fruit is more exposed to soil erosion. Differences in values next to and in between the plants are higher under dragon fruit. Therefore, it can be assumed that under peanut, nutrient concentrations are more balanced over the whole field. Due to a rising demand for food and pressure on land not yet used for agriculture, further research on Arenosols and the implementation of agricultural practices adapted to environmental conditions should be accelerated in order to achieve the SDGs (Sustainable Development Goals).

## RESUMEN

*La degradación del terreno ocasionada por factores humanos y climáticos conduce a la desertificación y da lugar a una reducción de la cubierta vegetal, erosión, y una pérdida de la fertilidad del suelo seguida de problemas socioeconómicos. En particular, las prácticas inapropiadas de uso del terreno son factores clave responsables de la desertificación. Este estudio examina la influencia de estrategias de sostenibilidad en el cultivo de la pitahaya y el cacahuete en Bình Thuân, Vietnam, sobre la fertilidad del suelo en una región que se caracteriza por presentar Arenosoles bajo un clima semiárido. La zona costera es propensa a la desertificación, lo que complica la producción agrícola. Con este objetivo, se combinaron análisis de varios parámetros edáficos con encuestas socioeconómicas basadas en la evaluación de entrevistas cuantitativas y un análisis FODA. Los resultados indicaron que no se pueden medir efectos*

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*significativos de las estrategias sostenibles sobre la fertilidad del suelo. Más aún, no se encontraron evidencias de que la intercalación de cultivos aumente la fertilidad del suelo, ya que los parámetros del suelo no fueron más elevados bajo pitahaya intercalada con cacahuete que bajo monocultivo. La mayor concentración de nutrientes observada junto al cultivo de la pitahaya muestra que este cultivo contribuye más a la fertilidad del suelo que el cacahuete. Esto se debe especialmente a la aplicación de mulch alrededor de la planta, lo que incrementa el contenido en humus del suelo y disminuye el lavado de nutrientes. Sin embargo, la zona no cultivada entre las plantas de pitahaya está más expuesta a la erosión del suelo. Las diferencias entre los valores de erosión junto a las plantas y entre ellas son más elevadas bajo el cultivo de pitahaya. En consecuencia, se puede asumir que las concentraciones de nutrientes bajo cultivo de cacahuete están más equilibradas a lo largo de todo el campo de cultivo. Debido a la demanda creciente de alimentos y a la presión sobre terrenos todavía no utilizados con fines agrícolas, se necesitan más estudios sobre los Arenosoles y la implementación de prácticas agrícolas adaptadas a las condiciones medioambientales que permitan alcanzar los objetivos de desarrollo sostenible (ODS).*

**RESUMO**

*A degradação das terras determinada por fatores humanos e climáticos conduz à desertificação e resulta na redução do coberto vegetal, erosão e perda da fertilidade do solo seguida de problemas socioeconómicos. Em particular, as práticas não ajustadas ao uso da terra são fatores chave responsáveis pela desertificação. O presente estudo avalia a influência de estratégias de sustentabilidade no cultivo da pitaia (fruta do dragão) e do amendoim em Bình Thuân, Vietname, sobre a fertilidade do solo numa região que se caracteriza por apresentar Arenossolos e clima semi-árido. A zona costeira é propícia à desertificação, o que complica a produção agrícola. Com este objetivo, combinaram-se várias análises de solos com uma avaliação sócio científica baseada na avaliação de entrevistas quantitativas e uma análise SWOT. Os resultados indicaram que não se podem medir os efeitos significativos de estratégias de sustentabilidade na fertilidade do solo. Além disso, não se encontraram evidências de que a intercalação de culturas aumente a fertilidade do solo, já que os parâmetros do solo não foram mais elevados com a cultura de pitaia intercalada com amendoim do que com a monocultura. A maior concentração de nutrientes observada junto às plantas de pitaia mostra que esta cultura contribui mais para a fertilidade do solo do que a do amendoim. Este facto, é especialmente devido à aplicação de mulch em volta da planta, o que aumenta o conteúdo em húmus do solo e diminui a lixiviação de nutrientes. Contudo, a área não cultivada entre as plantas de pitaia está mais exposta à erosão do solo. As diferenças entre os valores de erosão nas áreas junto e entre as plantas são mais elevadas na cultura de pitaia. Consequentemente, pode assumir-se que as concentrações de nutrientes nas áreas cultivadas com amendoim estão mais equilibradas em todo o campo de cultura. Devido à procura crescente de alimentos e à pressão sobre os terrenos que não são ainda usados para fins agrícolas, são necessários mais estudos sobre os Arenossolos e a implementação de práticas agrícolas adaptadas às condições ambientais deve ser acelerada de modo a permitir alcançar os Objetivos de Desenvolvimento Sustentável (ODS).*

**KEY WORDS**
**Agriculture, land degradation, Arenosols, desertification.**

**PALABRAS CLAVE**
Agricultura, degradación de tierras, Arenosoles, desertificación.

**PALAVRAS-CHAVE**
Agricultura, degradação de terras, Arenossolos, desertificação.

# 1. Introduction

Desertification is “the degradation in the arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities” (UNCCD 2002). Direct causes include maladjusted cultivation, deforestation, overgrazing and inappropriate irrigation practices; indirect causes comprise population pressure and poverty in conjunction with economic and political reasons. Because of the destruction of the vegetation cover, soil surface runoff, which might result in gully erosion, increases (Smith and Koala 1999). The process of desertification has a durable and possibly irreversible effect on the production potential of an environment and occurs due to human exploitation as well as ecological fragility of a region (Kassas 1995; Le Houérou 1996; Smith and Koala 1999; UNCCD 2006). Dryland areas cover almost one half (47.2%) of the global land surface. These terrestrial ecosystems are very sensitive and around 60% are prone to or affected by desertification, being subject to changes in the water regimes, vegetation and soil properties (Lal 2004; D'Odorico et al. 2013) Many of these drylands are characterised by low soil fertility, organic matter and water holding capacity (Parr et al. 1990). Due to insufficient vegetation cover, soils are easily affected by wind and water erosion, which results in shallow and infertile soils and consequently in decreased plant productivity (Verstraete et al. 2009). Soils in drylands are often susceptible to physical and chemical degradation, i.e. deterioration of soil structure and soil fertility, soil compaction, crusting, nutrient imbalance and acidification (Lal 2001).

According to Lockeretz (1988), the concept of sustainable agriculture encompasses problems, such as soil degradation, decreasing farm yields, environmental contamination by pesticides and the shortage of non-renewable resources. Based on low-input methods and skilled management, i.e. a minimised use of synthetic chemical fertilisers and pesticides, soil and water conservation practices, crop rotations, manure application, intercropping and conservation tillage, sustainable agriculture should enhance farming practices that conserve the environment and reduce soil erosion as well as nutrient losses together with a restoration of soil fertility in the long-term (Parr et al. 1990; Wilson and Lovell 2016).

Especially in regions prone to desertification, sustainable development is essential not only for ensuring food security for the current population, but also for preserving the environment for future generations (WCED 1987). The introduction of the Sustainable Development Goals (SDG) (UN 2017) highlighted the need to protect the environment and natural resources in response to, in alia, climate change, pressures in coastal areas, agriculture, desertification, loss of biodiversity and loss of forests.

The objective of this work is to explore how peanut and dragon fruit cultivation under local agricultural practices in the dryland region of the coastal plains of Bình Thuận, Vietnam, influences soil properties and whether there is an effect of the applied sustainable strategies on soil fertility in this coastal dryland area. In Bình Thuận province, which is situated in South Central Coastal Vietnam, almost half of the population aged 15 years or older is employed in the agricultural sector (General Statistic Office Vietnam 2010). However, agriculture has been subjected to a tremendous change as a result of desertification which often causes a reduction in yield and productivity, a shift of agro-ecological zones and a decrease in soil fertility (UNCCD 2006).

# 2. Material and Methods

## 2.1. Study area

The study area is situated in Bình Thuận province in the communes Hàm Đức, Hằng Phong and Hòa Thắng, between 108°8'20.4'' – 108°30'10.8''E and 11°0'28.8'' – 11°7'37.2''N, bordering the South China Sea in the East (**Figure 1**). The climate is characterised as arid to semi-arid during the dry season and dry sub-humid due to monsoonal events from May to October. Related to the orographic situation of Bình Thuận, winds are blocked by the Trường Sơn mountains and prevent precipitation which has a reinforcing effect on the dry season from November to April. (Pham et al. 2012). The mean annual temperature at Phan Thiết weather station – the capital of Binh Thuan located at the coastal area – is 27.17 °C and mean annual precipitation is 1 142.58 mm, even though in some areas it can be lower with only 550 mm per year (Hountondji et al. 2012).

The geology in the research area is characterised by hard rocks of Cretaceous rhyolite and dacite,

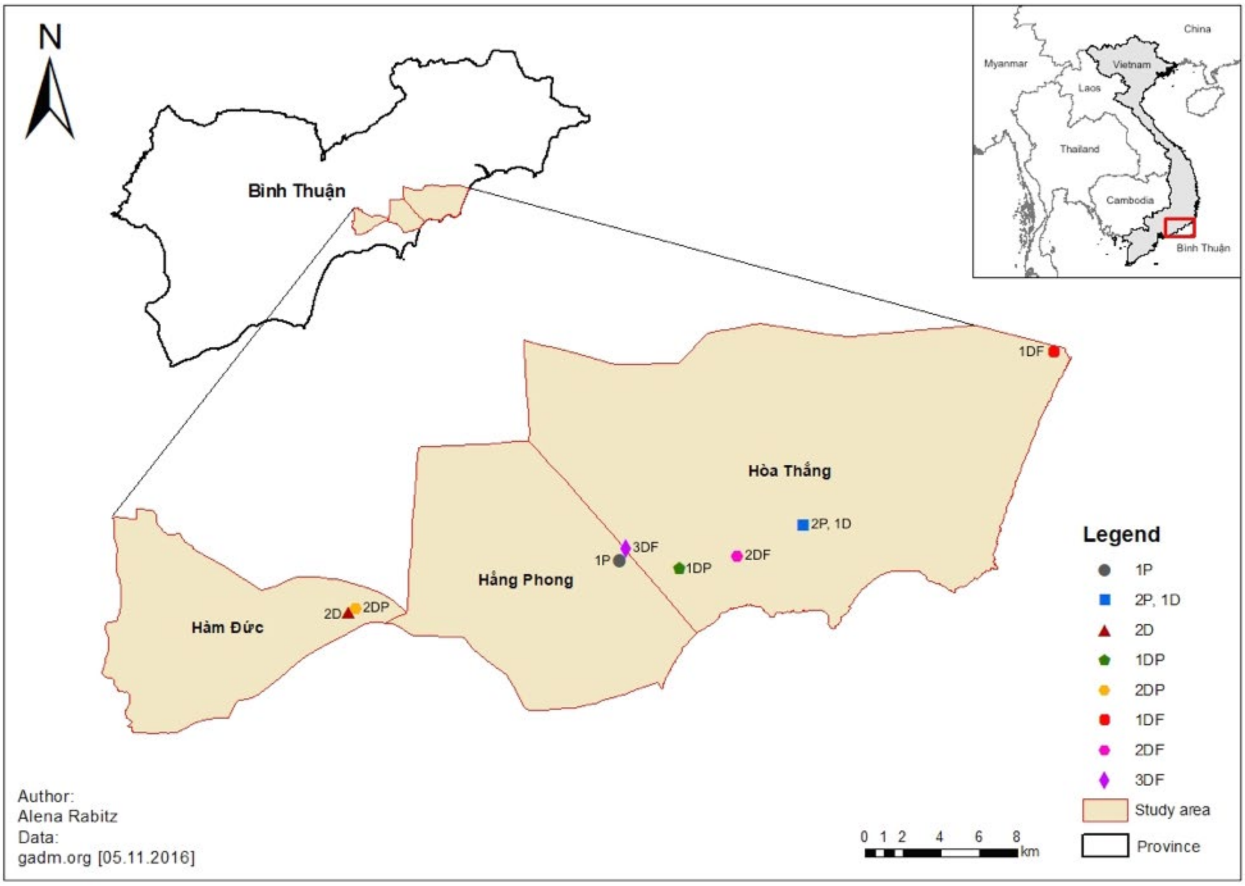


**Figure 1.** Schematic map of the study area in Bình Thuận Province, Vietnam, showing the location of the sampling sites: P - peanut, D - dragon fruit, DP - dragon fruit intercropped with peanut and DF – uncropped area degraded field.

which are covered with widespread sandy coastal barrier successions from the Late Pleistocene and Holocene (Nguyen et al. 2009). Two coastal barriers have emerged in the area – the older inner barriers consisting of red sand with underlying white sand and the younger outer barriers comprised of unconsolidated yellow white sand (Murray-Wallace et al. 2002; Dam et al. 2009). According to the IUSS Working Group WRB (2015), the main soil type in the study area can be defined as rhodic and haplic Arenosols. In the Vietnamese soil classification, sandy soils can be divided into white and yellow sand dune soils, red sand dune soils and sandy marine soils (MARD 2002).

## 2.2. Soil sampling

18 profiles (154 samples) were taken on four randomly selected farms under different crops. Each of the following crops was considered twice in the survey: peanut (1P&2P), dragon fruit (1D&2D), dragon fruit intercropped with peanut (1DP&2DP). Furthermore, samples were taken on three uncropped areas, called degraded fields (DF). In **Table 1** a detailed overview on soil sites and profiles is given. Samples were taken with a Pürkhauer (drilling device, diameter 2 cm) from two soil profiles on each site. On the farms one profile was taken directly next to the plant and the other one in between the plants. The sampling interval was 5 cm down to a depth of 20 cm, continuing with an interval of 10 cm to a depth of 100 cm from the surface. Because of the coarse soil texture and low organic carbon content as well as the already dry condition of

**Table 1.** Site characteristics

| Site | Soil Profile | Farm no. | Profile Type | Coordinates (DD) | | Land Cover | Soil Type | Soil Colour (Munsell) |
|---|---|---|---|---|---|---|---|---|
| | | | | N | E | | | |
| 1P | 1P1<br>1P2 | 1 | next<br>in between | 11.05139 | 108.49327 | Peanut | haplic Arenosol | brown<br>brown |
| 2P | 2P1<br>2P2 | 2 | next<br>in between | 11.06506 | 108.39150 | Peanut | haplic Arenosol | yellowish red<br>yellowish red |
| 1D | 1D1<br>1D2 | 2 | next<br>in between | 11.06506 | 108.49252 | Dragon fruit | rhodic Arenosol | red<br>red |
| 2D | 2D1<br>2D2 | 4 | next<br>in between | 11.03250 | 108.34384 | Dragon fruit | haplic Arenosol | pinkish gray<br>pinkish gray |
| 1DP | 1DP1<br>1DP2 | 3 | next<br>in between | 11.04911 | 108.49358 | Dragon fruit with Peanut | haplic Arenosol | yellowish red<br>yellowish red |
| 2DP | 2DP1<br>2DP2 | 4 | next<br>in between | 11.03367 | 108.49687 | Dragon fruit with Peanut | haplic Arenosol | pinkish/light gray<br>(pinkish) gray |
| 1DF | 2 | . | . | 11.12968 | 108.49660 | Degraded Field | haplic Arenosol | reddish yellow |
| 2DF | 2 | . | . | 11.05342 | 108.37768 | Degraded Field | rhodic Arenosol | red |
| 3DF | 2 | . | . | 11.05616 | 108.33637 | Degraded Field | haplic Arenosol | yellowish red |

the soil (due to a long period without rain before soil sampling), samples were air dried for 48 hours. Subsequently the collected samples were sieved with a 2 mm mesh size analytical sieve (according to Austrian Standard L-1060 (2004)) and transported in plastic bags to the laboratory for further analyses.

### 2.3. Interviews

Interviews were conducted with 15 local farmers in the research area. For the evaluation of the interviews by means of an indicator system, the interview questions were subdivided into four parts including (A) Implementation of sustainable agricultural practices, (B) Awareness of land degradation, (C) Knowledge and perceptions of organic farming and (D) Farm characteristics. By comparing the farms to a hypothetical most sustainable farm, points were awarded for each response and summarised for every chapter. If a respondent declined to answer, the same or a lower amount of points as for the worst option was awarded since missing awareness of the matter was assumed.

To evaluate the effect of sustainability strategies on soil fertility, one farm in each crop class – peanut (P), dragon fruit (D) and dragon fruit with peanut (DP) - was categorised as more sustainable and the other one as less sustainable. More sustainable means closer to a hypothetical most sustainable farm. The sustainability depends on the application of agricultural practices having a positive influence on crop growth, including crop rotation, use of organic fertilisers and pesticides, choice of resistant plants, tillage practices, drainage systems, conservation practices and the return or compost of residues (Parr et al. 1990; Wilson and Lovell 2016). Therefore, the more of these sustainable practices were applied, the higher a farm was graded, resulting in a ranking of the four farms from very low, low, moderate, high to very high. Since mulch was applied only on dragon fruit and not on peanut, this sustainability strategy was not part of the overall evaluation. The outcomes of this classification were compared to those of the soil analyses to detect if soil parameters are more adequate for crop production of the examined crops on the sustainable farms.

Moreover, the results of the interviews of the four farms where soil samples were taken, were summarised for illustration in a SWOT analysis matrix (Groselj and Stirn 2015). For this, strengths, weaknesses, opportunities and threats concerning land degradation, sustainability strategies and farm characteristics in the area were presented in the four quadrants of the chart and completed with different symbols associated with each farm – depending on the answers in the interviews.

## 2.4. Physical and chemical soil analyses

Soil analyses comprised electrical conductivity (EC), pH, total carbon (TC), total nitrogen (TN), dissolved organic carbon (DOC), water extractable anions (WEA), the amount of acid extractable plant nutrients and soil colour.

Before measuring total organic carbon (TOC), the occurrence of inorganic carbon (IC) was determined with 10% HCl. Since this test was negative, it was concluded that negligible IC content exists in the soil, which implies that TC equalises TOC. Prior to the determination of TOC and total nitrogen (TN) samples were milled for five minutes in a Retsch MM 2000 Mill. TOC and TN were determined on a 1–1.8 mg sample using a Carlo Erber Elementary Analyser CNS NA1500 with dry combustion at 1800 ºC and analysis of the pyrolosis gases with a gas chromatograph thermal conductivity detection system (Austrian Standard L-1080 (1989) and Austrian Standard L-1082 (1982). Data were acquired with Agilent Chemstation 32. EC, pH, DOC and WEA were analysed in a water extract (solid liquid ratio 1:10) containing 3 g sieved soil and deionised water. The water extracts were prepared one day in advance of shaking them with a GFL 3015 shaker for one hour before filtering them gravimetrically with ashless filter paper (Whatmann TM, #40). In addition, samples had to be centrifuged to get rid of colloids. Soil acidity (pH) was determined by applying Austrian Standard procedure L-1083 (1989) at a temperature of 25 ºC with a calibrated pH meter (Mettler Toledo and SevenGo DuoTM SG23). EC was measured with a conductometer (WTW LF 191) at 25 ºC following Austrian Standard Procedure L-1092 (1993). The results were expressed in µS/cm.

The determination of water extractable anions was assayed with a liquid ion chromatic system from Metrohm, 881 Compact IC pro according to Austrian Standard L-1092 (1993). DOC was analysed with a PerkinElmer 2300 EnSpire Multimode Plate Reader based on UV absorbance at a wavelength of 245 nm based on the method of Brandstetter et al. (1996). The amount of acid extractable plant nutrients was analysed by an acid digest for nutrients with aqua regia. The element concentration was measured with atomic absorption spectroscopy (AAS Perkin Elmer PinAAkle 800T) using external standards (Ca, Mg, K, and Na) (Austrian Standard L-1085 1999). The soil colour was determined with air dried soil in the laboratory with a standard Munsell soil colour chart per Austrian Standard L–1071 (2005).

## 2.5. Statistical analyses

Descriptive analyses and statistical tests were conducted with Microsoft Excel and IBM SPSS Statistics 24. In advance of statistical analyses, data were tested for normal distribution with the Kolmogorov-Smirnov-Test and the Shapiro-Wilk-Test. Furthermore, a Levene test was used for analyses of homogeneity of variances. Since the data did not fulfil the requirements of normal distribution and homogeneity of variances, a pairwise comparison between groups was run with the non-parametric Mann-Whitney U-Test for two groups and the non-parametric Kruskal-Wallis-Test for more than two groups. The significance level for all tests was at $p < 0.05$. If differences between groups were significant, a Bonferroni post-hoc test, where results had to obtain adjusted significance to become valid, was carried out to examine variances between specific groups. Correlation and linear regression models were performed to investigate the relationships between different parameters. The correlation was analysed with a non-parametric Spearmen's rho test since the data was not normally distributed.

# 3. Results

### 3.1. Evaluation of sustainability strategies and awareness of land degradation

The results of the evaluation of the interviews by an indicator system showed that adapted agricultural practices, sustainable land management and environmental conditions over all interrogated farms in the research area are moderate (30 points out of 67), even though a low willingness of response of some farmers must be considered as well. Part (A) Implementation of sustainable agricultural practices can be rated between moderate and high (16 points out of 26; all farms apply at least one conservation practice on their fields and crop residues are mainly composted or returned to the farm. Just above half of the farms perform crop rotation and have drainage systems). The awareness of land degradation (B) is between moderate to high (6 points out of 11; the recognition of indicators of land degradation is high but the application of land degradation controls only moderate). Knowledge of organic farming (C) is well developed (3 points out of 5; apprehension of organic farming widely exists, although perceptions about organic farming characteristics and awareness of problems are low). Over the last ten years, soil quality and fertility in the research area have decreased and natural conditions can be characterised as unprofitable (D – farm characteristics, 6 points out of 25).

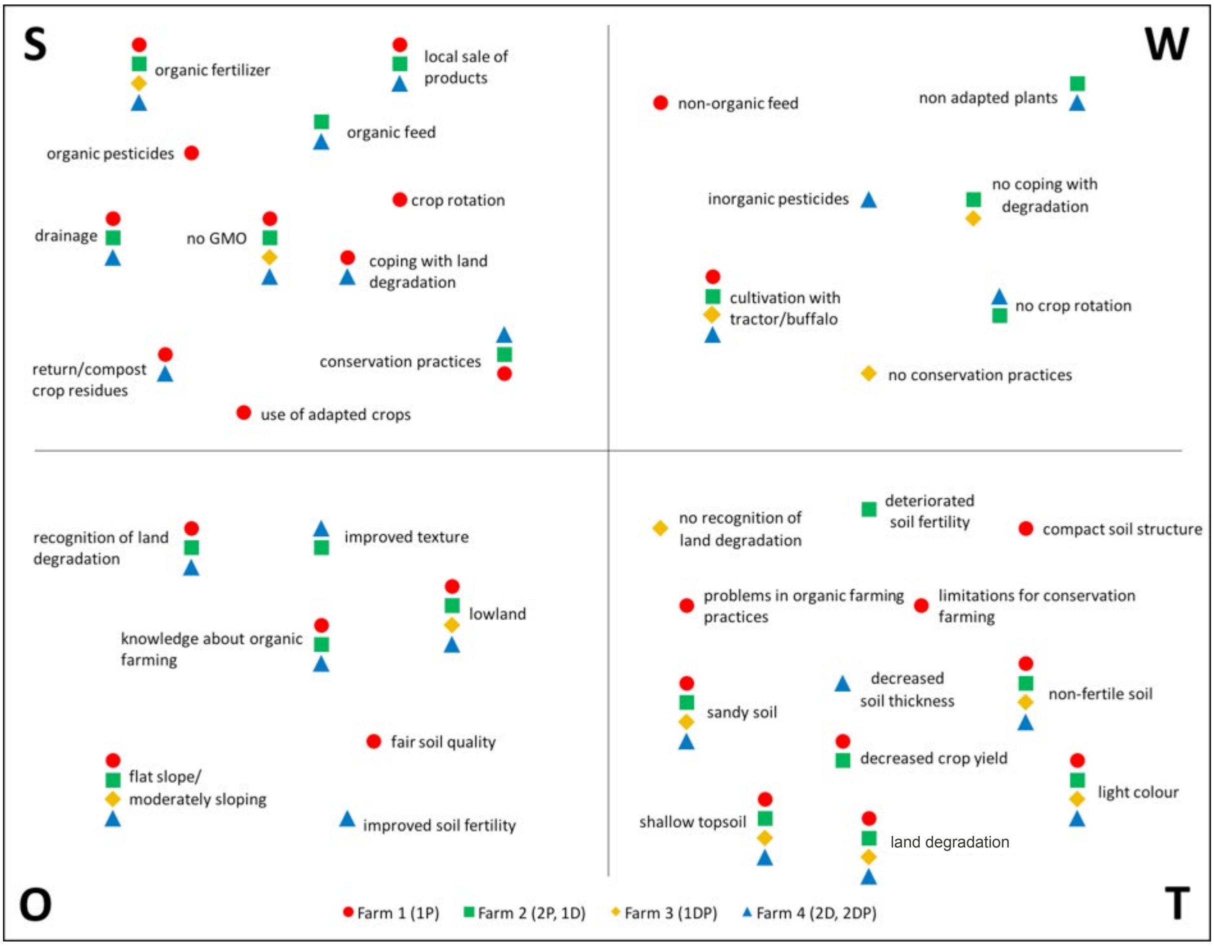


**Figure 2.** SWOT matrix. Quadrants show the strengths (top left), weaknesses (top right), opportunities (bottom left) and threats (bottom right) of the four farms; the symbols highlight a correlation between the farms and a particular factor. (P = peanut, D = dragon fruit, DP = dragon fruit with peanut)

### 3.2. SWOT analysis

The SWOT analysis shows the strengths, weaknesses, opportunities and threats of each farm (spatial location of indicators in the four quadrants of the chart are randomly distributed) (**Figure 2**). Strengths and weaknesses refer to internal farm characteristics and can be changed by the decisions of the farmers themselves. The farms in the research area reveal strengths through the implementation of sustainability strategies, i.e. the application of organic fertilisers or conservation practices. In contrast, weaknesses occur through the cultivation of fields by tractor or buffalo or no adoption of conservation practices and crop rotation. Opportunities and threats, respectively, develop through soil parameters, including soil quality, texture and fertility. Due to disadvantageous natural conditions, which are worsened through inappropriate agricultural practices, threats are widely spread in the area. Strengths are especially important since they might counteract potential threats.

### 3.3. Soil fertility

Mean $pH_{H_2O}$ over all sites and depths is 6.45 (**Table 2**). Mean electrical conductivity is 50.39 µS/cm, the highest values occur under D and DP with maxima of 180.13 and 265.28 µS/cm, respectively, at a depth of 5 cm. Mean TN values are very low at 0.03%, while the lowest mean values can be found under P and the uncropped area DF (0.02%). Mean $NO_3^-$ content over all sites is 26.95 mg/kg, being highest under DP (36.57 mg/kg) and D (49.86 mg/kg). Values above 30 mg/kg suggest adequate levels of $NO_3^-$ which applies only at sites D and DP but not for P (19.84 mg/kg) (Hazelton and Murphy 2007). Overall, mean TOC content is low at 0.60%. The highest mean value is 1.09% under dragon fruit, the smallest mean TOC content occurs under peanut (0.32%) and the uncropped area (0.33%). TOC and TN contents in the research area show a strong significant correlation coefficient of 0.740 ($p < 0.01$) (**Figure 3**).

**Table 2.** Mean soil parameters over all crop classes (Total), P (peanut), D (dragon fruit), DP (dragon fruit intercropped with peanut) and uncropped area (DF)

| | Total | P | D | DP | DF |
|---|---|---|---|---|---|
| | Mean | Mean | Mean | Mean | Mean |
| TN [%] | 0.03 | 0.02 | 0.06 | 0.04 | 0.02 |
| TOC [%] | 0.60 | 0.32 | 1.09 | 0.74 | 0.33 |
| C:N ratio | 19.92 | 18.56 | 20.55 | 20.50 | 20.16 |
| DOC [mg/l] | 16.71 | 8.30 | 30.41 | 25.69 | 6.60 |
| $Cl^-$ [mg/kg] | 38.15 | 35.10 | 43.45 | 48.58 | 28.02 |
| $NO_3^-$ [mg/kg] | 26.95 | 19.84 | 36.57 | 49.86 | 7.00 |
| $PO_4^{3-}$ [mg/kg] | 36.30 | 11.99 | 64.94 | 71.07 | 3.00 |
| $SO_4^{2-}$ [mg/kg] | 19.08 | 13.44 | 21.08 | 40.34 | 5.39 |
| Ca [mg/kg] | 276.25 | 107.64 | 373.43 | 281.66 | 2.70 |
| Mg [mg/kg] | 210.45 | 33.75 | 182.99 | 310.94 | 15.70 |
| K [mg/kg] | 181.43 | 97.04 | 224.83 | 182.67 | 62.40 |
| Na [mg/kg] | 56.20 | 101.18 | 66.73 | 64.45 | 6.13 |
| EC [µS/cm] | 50.39 | 39.99 | 69.37 | 81.54 | 19.29 |
| $pH_{H_20}$ | 6.45 | 6.34 | 6.49 | 6.62 | 6.38 |

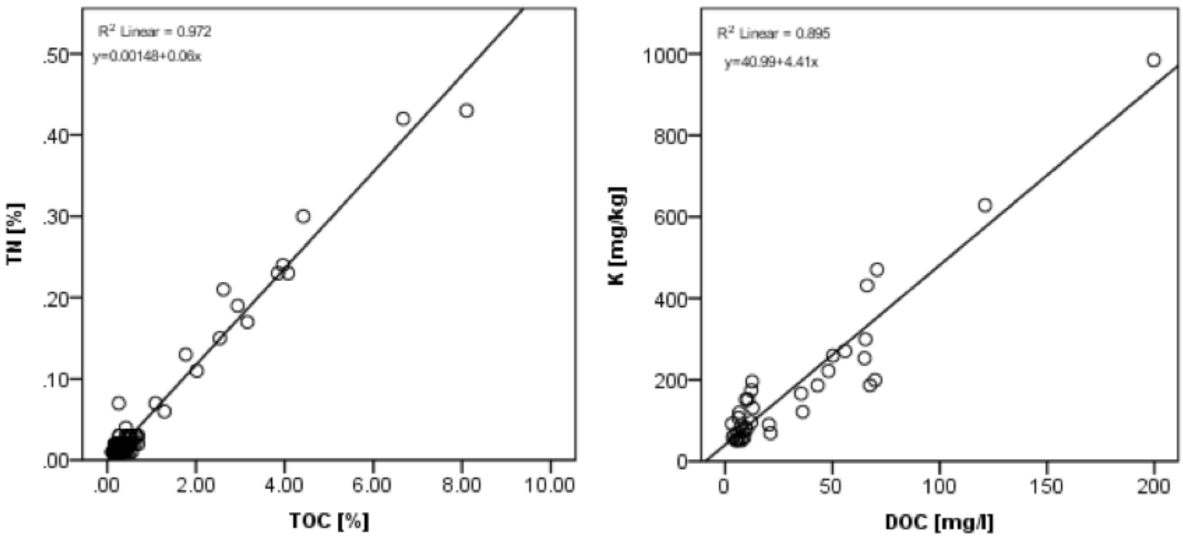


**Figure 3.** Regression between TOC and TN content as well as K content and DOC concentration; n = 154.

Mean DOC is 16.71 mg/l, highest values can be found under D and DP. DOC has a highly significant positive correlation ($p < 0.01$) with TN, TOC, $NO_3^-$, $PO_4^{3-}$, $SO_4^{2-}$, cation content, EC and pH. A high correlation exists between DOC concentration and K content with a strong significant correlation coefficient of 0.854 ($p < 0.01$) (**Figure 3**).

Mean $Cl^-$ content over all sites is very low at 38.15 mg/kg, being highest in class D (43.45 mg/kg) and DP (48.58 mg/kg) (Blume et al. 2010; Horneck et al. 2011). Mean $PO_4^{3-}$ content is moderate at 36.30 mg/kg, while DP (71.07 mg/kg) and D (64.94 mg/kg) record the maximum mean values (Hazelton and Murphy 2007). Mean content of $SO_4^{2-}$ is very low at 19.08 mg/kg with the highest values under DP (40.34 mg/kg) and D (21.08 mg/kg) (Blume et al. 2010). Mean cation contents are as follows: Ca – 276.25 mg/kg; Mg – 210.45 mg/kg; K – 181.43 mg/kg and Na – 56.20 mg/kg. Mean K and Mg content over all sites can be described as moderate, whereas mean Mg content under DP is high at 593.78 mg/kg. Na content is low and Ca content very low (Hazelton and Murphy 2007; Cilliers 2011). The highest correlation coefficient appears between Mg and K of 0.905 ($p < 0.01$).

# 4. Discussion

## 4.1. Effect of soil fertility and nutrient availability on agricultural cultivation

Overall, the investigated farms show low soil fertility. Due to the climate, agricultural production is limited to crops adapted to dry conditions. The higher TOC values under D (1.09%) and DP (0.74%) compared to the average values of all examined farms (0.60%) induce good soil structure and stability and can be explained by the application of mulch around the dragon fruit plant (Lal 2001; Hazelton and Murphy 2007). Pham (2010) showed TN contents for Vietnamese sandy soils under agricultural cultivation that were, with 0.05-0.06%, slightly higher than average values in the research area (0.03%). Furthermore, Pham (2010) compared the TOC content of different soils in Vietnam showing the lowest mean values under sandy soils with 0.68%, which is similar to the mean value in the research area (0.60%) (Pham 2010). The soil survey of Nguyen (2005) was carried out in four communes of Bac Binh district, Binh Thuan. Average TOC values of all four communes were 0.59%, which is the same as in the research area. In contrast, TN was twice as high (0.06%) (Nguyen 2005). For a further study in Binh Dinh province, soil samples were taken under peanut cultivation. On peanut site 1, pH results were slightly lower in the study than in the research area (6.1 vs. 6.34), while EC was the same with 40.00 µS/cm. TOC content was 0.32% in the research area compared to 0.09% and 0.11% in the study (Hoang et al. 2015). Another survey tested the soil properties of sandy soils for the suitability of peanut cultivation in Ninh Thuan province. Results showed a similar mean TOC in Phuoc Dinh, Ninh Thuan (0.33%) and under peanut in the research area (0.32%) (Hoang et al. 2015).

For agricultural cultivation a sufficient anion and cation content is necessary and especially for peanuts, low Na and Ca content can lead to constraints in crop growth (Hazelton and Murphy 2007). Nutrient requirements for peanuts are more than 50 mg/kg K, 8 mg/kg P and 100 mg/kg Ca and micronutrients, such as Zn, Fe and Cu (Thai Agricultural Standard 2010). Since Ca is a growth limiting nutrient, fertilisation is often required for a rise in yields (Mbonwa 2013; Cilliers 2011).

The study of Pham (2010) stated the following cation concentrations for Vietnamese sandy soils: 138.00 mg/kg Ca (0.69 $cmol_c$/kg); 30.38 mg/kg Mg (0.25 $cmol_c$/kg); 64.40 mg/kg Na (0.28 $cmol_c$/kg) and 11.73 mg/kg K (0.03 $cmol_c$/kg). In comparison to the concentrations measured in the research area, Na values were higher in this study, whereas the other amounts were lower (Pham 2010). Sandy soils on marine sediments used for cultivation of crops, such as cassava, coconut and peanut in Hainan Island, China, showed similar pH and TOC values, even though TOC and TN content as well as Na concentration was slightly higher than in the research area. In contrast, Mg and K concentration was lower (72.6 and 78.00 mg/kg in comparison to 210.45 and 181.43 mg/kg in the research area) (Zhao et al. 2005).

Mean pH in the research area is slightly acidic to neutral (6.45) and mean EC non-saline (50.39 µS/cm) and therefore both appropriate for farming practices (Hazelton and Murphy 2007; Horneck et al. 2011; Mashimbye et al. 2012; Bell et al. 2015; USDA 2017).

### 4.2. Degraded field and cropland

A comparison of the uncropped area degraded field (DF) and cropland shows significant differences in DOC concentration, anion and cation content and EC. All values are higher under crops than on degraded field (**Figure 4**). For DOC, $NO_3^-$, $PO_4^{3-}$, $SO_4^{2-}$ and EC, soil properties differ significantly between DF and the other classes P, D and DP.

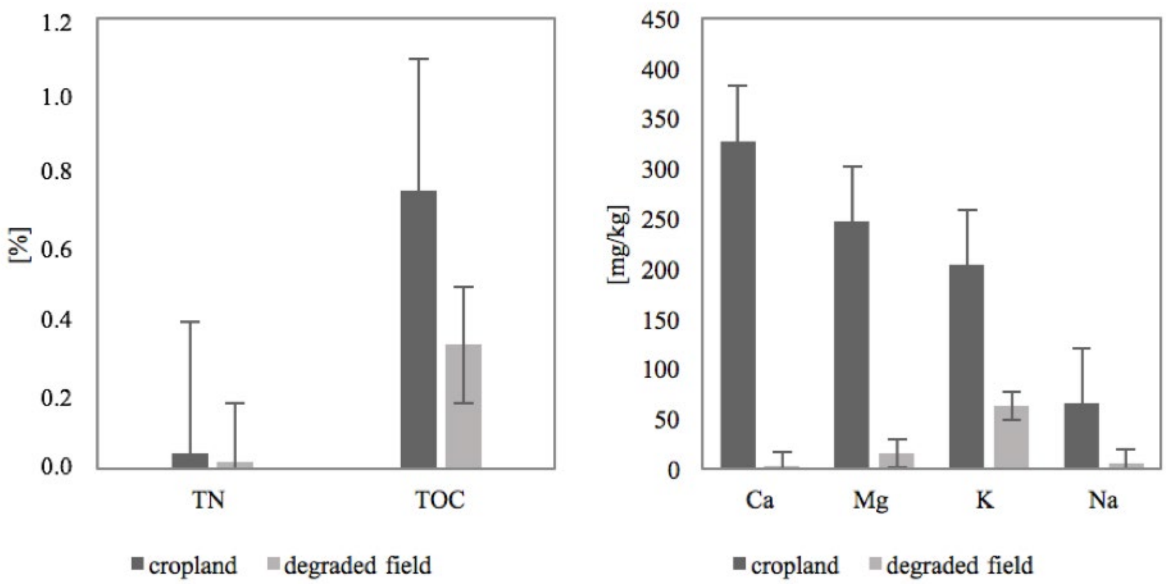


**Figure 4.** Comparison between soil parameters under cropland and degraded field. Error bars show the standard error.

### 4.3. Next to the plant and in between the plants

Vegetation cover counteracts soil erosion and enhances soil quality and SOC content (Lal 2001). Similar to other studies, values in the research area are always higher next to the plant than in between the plants (**Figure 5**) (Montaña et al. 1988; Tongway and Ludwig 1990; Dunkerley 2011).

Significant differences between next to the plant and in between the plants occur for TN, TOC, C:N ratio, DOC, $NO_3^-$, $PO_4^{3-}$, $SO_4^{2-}$, cation content and EC. These differences are especially distinctive under D and DP. This may be a result of the application of mulch around the dragon fruit plant, which may reduce water and fertiliser loss, serve as weed control and keep nutrients from leaching (Luders and McMahon 2006; Crane and Balerdi 2016). A higher concentration of soil nutrients contributing to plant growth around the dragon fruit indicates that dragon fruit cultivation contributes more to soil fertility than peanut cultivation. However, these outcomes refer only to samples taken directly next to the plant. Due to a bigger space between the individual dragon fruit plants and missing leaf cover, the soil surface may be more exposed to possible erosion and leaching under dragon fruit than under peanut. In addition, differences between next to the plant and in between the plants are higher under dragon fruit, indicating that on the peanut field values are more balanced (Creswell and Martin 1998; Phan and McKay 2015).

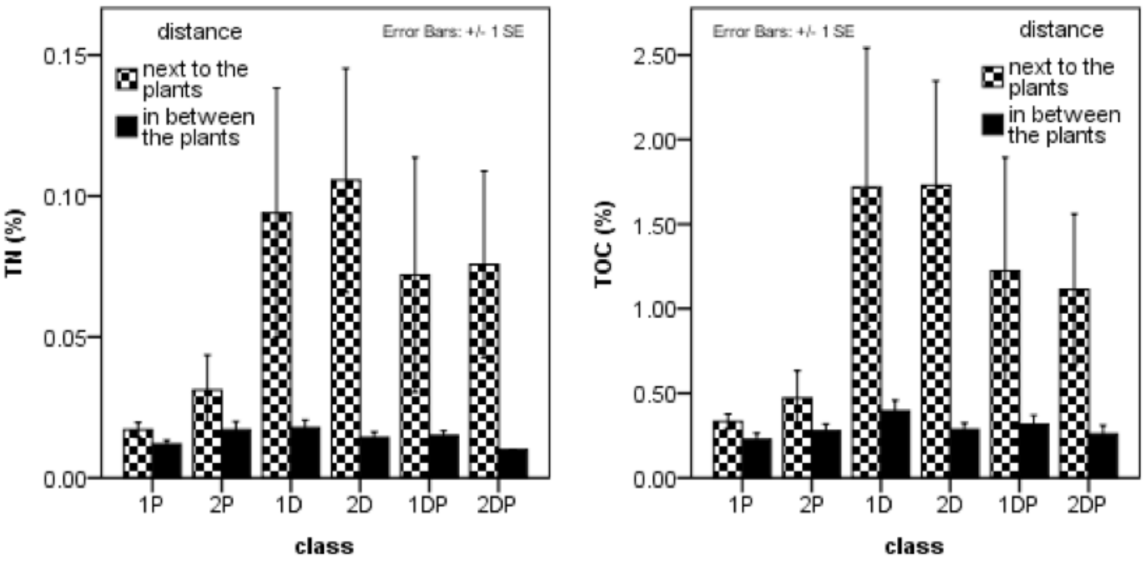


**Figure 5.** Comparison of TN and TOC content between next to and in between the plants. Error bars show the standard error.

### 4.4. Effects of intercropping on soil fertility

Intercropping is "the simultaneous cultivation of multiple crop species in a single field" (Vandermeer 1989). For the examination of the effects of intercropping on soil fertility, values measured in between the plants were compared between dragon fruit sites with peanut intercropping (DP2) and without intercropping (D2 - dragon fruit monoculture). The results in the research area show that measured values are not significantly higher with intercropping, except for $Cl^-$. The pH-values are the same among both cultivation systems. The greatest differences appear in K, the lowest in TN content (**Figure 6**).

The hypothesis that intercropping with peanuts enhances soil fertility has to be rejected since no significant differences in TN, TOC and other soil nutrients' content between dragon fruit intercropped with peanut and without intercropping occur.

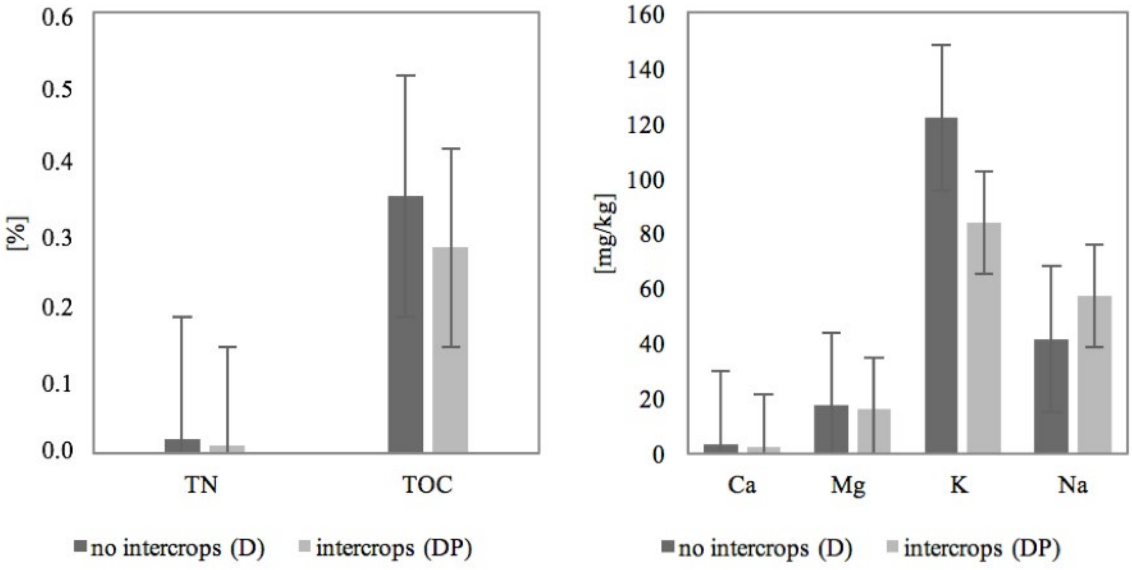


**Figure 6.** Comparison of soil parameters between no intercrops (D – dragon fruit monoculture) and intercrops (DP – dragon fruit with peanut). Error bars show the standard error.

Nevertheless, intercropping might have positive effects on other parameters, such as erosion and additional yields due to the intercrops (Phan and McKay 2015). Soil erosion is increased by inappropriate agricultural practices, e.g. the removal of the vegetation cover. The growing of peanuts might counteract erosion as they possess a dense canopy that deflects the impact of heavy rainfall (Creswell and Martin 1998; Phan and McKay 2015). However, as intercropping increases both work load and costs, monoculture is often preferred (Van de et al. 2008).

### 4.5. Effect of sustainability strategies on soil fertility

For each crop class (P - peanut, D - dragon fruit and DP – dragon fruit with peanut), two farms were compared, one of them being rated as more sustainable and the other one less (**Table 4**), depending on the application of agricultural practices, such as crop rotation, use of organic fertilisers and pesticides, choice of resistant plants, tillage practices, drainage systems, conservation practices and the return or compost of residues (**Table 3**), having a positive influence on crop growth.

**Table 3.** Adoption of sustainability strategies; (yes = 1 point; no = 0 points)

| Sustainability strategies | Farm 1 | Farm 2 | Farm 3 | Farm 4 |
|---|---|---|---|---|
| Crop rotation | yes | no | no | no |
| Organic fertilisers | yes | yes | yes | yes |
| Resistant plants | yes | no | no | no |
| Drainage systems | yes | yes | no | yes |
| Conservation practices | yes (2) | yes (1) | no | yes (1) |
| Return & compost residues | yes | no | no | yes |
| SUM | 7 | 3 | 1 | 4 |

In class P, significant differences were found in $NO_3^-$, Al and Fe concentration. $NO_3^-$ concentration was higher on the less sustainable, Al and Fe concentration on the more sustainable farm. The less sustainable farm overall had higher values than the sustainable one. In class D, significant differences were only detected in pH-value, which was higher on the farm operating less sustainably. Furthermore, most of the values were higher on the farm with the less sustainable performance. $Cl^-$ concentration differed significantly in class DP between the two farms, being elevated on the farm with increased application of sustainability strategies, which also shows a few values that are higher than on the less sustainable farm (**Table 4**).

Moreover, the four farms were ranked by the adoption of sustainability strategies (**Table 5**). The performance of farm 1 was rated with "very high", farm 4 "high", farm 2 "moderate" and farm 3 "low". Significant differences between the farms occur regarding DOC (between farm 1 and 2) and $Cl^-$ content (between farm 3 and 1, 2 as well as 4). Highest values occur primarily on the farms with a low (farm 3) and high (farm 4) adoption of sustainability strategies, whereas lowest values appear mostly on the very high rated farm (farm 1).

Thus, in this study, we could not find any effects of the measured sustainability strategies on soil fertility. However, other factors such as the amount of applied fertiliser or the responsiveness of the interviewees might have an influence. Furthermore, also the type of crop probably plays an important role, since values are frequently higher on the farms that grow dragon fruit. There also might be an effect of the soil colour, since farm 4 on white soil performs best and a comparison between red and white sandy soil showed except for Ca, Mg and K concentrations higher values on white sandy soil (**Table 6**). These outcomes contrast with Nguyen (2005), who detected an increase of soil chemical properties including TC, TN, total P and K together with available P, K and Ca, on red sandy soil as well as Mg being higher on white sandy soil (Nguyen 2005).

**Table 4.** Comparison of farms performing more or less sustainable agricultural practices

| | P | | D | | DP | |
|---|---|---|---|---|---|---|
| | Less sustainable Farm 2 (2P) | More sustainable Farm 1 (1P) | Less sustainable Farm 2 (1D) | More sustainable Farm 4 (2D) | Less sustainable Farm 3 (1DP) | More sustainable Farm 4 (2DP) |
| TN [%] | 0.02 | 0.01 | 0.06 | 0.07 | 0.04 | 0.04 |
| TOC [%] | 0.37 | 0.28 | 1.09 | 1.10 | 0.77 | 0.69 |
| C:N ratio | 17.38 | 19.69 | 21.15 | 19.84 | 19.82 | 21.48 |
| DOC [mg/l] | 9.43 | 7.27 | 38.14 | 22.69 | 26.27 | 24.99 |
| $Cl^-$ [mg/kg] | 36.65 | 33.62 | 52.84 | 31.71 | 17.55 | 92.92 |
| $NO_3^-$ [mg/kg] | 25.25 | 14.71 | 17.58 | 61.88 | 13.10 | 102.37 |
| $PO_4^{3-}$ [mg/kg] | 10.98 | 12.95 | 45.83 | 88.84 | 41.55 | 113.23 |
| $SO_4^{2-}$ [mg/kg] | 12.95 | 13.90 | 18.66 | 24.11 | 20.33 | 68.92 |
| Ca [mg/kg] | . | . | 376.25 | 370.62 | 427.56 | 135.76 |
| Mg [mg/kg] | . | . | 295.36 | 70.61 | 479.65 | 142.24 |
| K [mg/kg] | . | . | 321.46 | 128.19 | 192.70 | 172.63 |
| Na [mg/kg] | . | . | 72.66 | 60.81 | 58.32 | 70.57 |
| EC [µS/cm] | 41.20 | 38.85 | 72.55 | 65.39 | 60.80 | 111.16 |
| $pH_{H_20}$ | 6.37 | 6.32 | 6.67 | 6.26 | 6.46 | 6.86 |

**Table 5.** Ranking of farms by the adoption of sustainability strategies

| | Low (Farm 3) | Moderate (Farm 2) | High (Farm 4) | Very high (Farm 1) |
|---|---|---|---|---|
| Fertiliser [kg/ha/yr] | 600 | 2400 | 200 | 600 |
| Type of Fertiliser | NPS | K | NPK | K |
| Crop | DP | D&P | D&DP | P |
| Colour | red | red | white | red |
| TN [%] | 0.04 | 0.04 | 0.06 | 0.01 |
| TOC [%] | 0.77 | 0.73 | 0.91 | 0.28 |
| DOC [mg/l] | 26.27 | 24.41 | 23.73 | 7.27 |
| $Cl^-$ [mg/kg] | 17.55 | 44.95 | 60.27 | 33.62 |
| $NO_3^-$ [mg/kg] | 13.1 | 21.31 | 81.43 | 14.71 |
| $PO_4^{3-}$ [mg/kg] | 41.55 | 28.85 | 100.22 | 12.95 |
| $SO_4^{2-}$ [mg/kg] | 20.33 | 15.88 | 45.02 | 13.90 |
| Ca [mg/kg] | 427.56 | 376.25 | 253.19 | 161.54 |
| Mg [mg/kg] | 479.65 | 295.36 | 106.43 | 40.11 |
| K [mg/kg] | 192.7 | 321.46 | 150.41 | 149.15 |
| Na [mg/kg] | 58.32 | 72.66 | 65.69 | 137.62 |
| EC [µS/cm] | 60.8 | 57.28 | 86.75 | 38.85 |
| $pH_{H_20}$ | 6.46 | 6.52 | 6.54 | 6.32 |

**Table 6.** Soil parameters differentiated by soil colour

| | white | red |
|---|---|---|
| TN [%] | 0.06 | 0.03 |
| TOC [%] | 0.91 | 0.63 |
| DOC [mg/l] | 23.73 | 20.51 |
| $Cl^-$ [mg/kg] | 60.27 | 35.15 |
| $NO_3^-$ [mg/kg] | 81.43 | 17.56 |
| $PO_4^{3-}$ [mg/kg] | 100.22 | 28.04 |
| $SO_4^{2-}$ [mg/kg] | 45.02 | 16.50 |
| Ca [mg/kg] | 253.19 | 401.91 |
| Mg [mg/kg] | 106.43 | 387.51 |
| K [mg/kg] | 150.41 | 257.08 |
| Na [mg/kg] | 65.69 | 65.49 |
| EC [µS/cm] | 86.75 | 53.50 |
| $pH_{H_20}$ | 6.54 | 6.46 |

## 5. Conclusions

This study examines soil fertility and sustainability strategies under dragon fruit and peanut cultivation in a dryland area in Bình Thuận, Vietnam, which is prone to desertification due to climatic factors and human impact, such as maladjusted cultivation methods. In the course of this study, soil analyses of peanut, dragon fruit, dragon fruit intercropped with peanut and degraded field were combined with a socio-scientific survey based on quantitative interviews and a SWOT analysis to scrutinise the effect of sustainability practices on soil fertility under the mentioned agricultural land uses.

In the research area, adapted agricultural practices, sustainable land management and environmental conditions can be rated as average. Potential opportunities on the farms are often threatened by low soil fertility as a result of disadvantageous natural conditions, which are further deteriorated through inappropriate agricultural practices.

The measured sustainability strategies did not show any effects on soil fertility. Furthermore, intercropping did not enhance nutrient concentration as expected, even though it might have positive effects on soil erosion control or additional cultivation area. Comparing soil fertility between samples taken next to the plant and in between the plants showed consistently higher values next to the plant. The same outcomes occurred for degraded field and cropland, where nutrient concentration for all measured soil parameters was increased. Because of higher nutrient deficiencies under peanut, it is estimated that dragon fruit contributes more to soil fertility than peanut cultivation, although the non-cultivated area in between the dragon fruit is more exposed to soil erosion and nutrient concentrations are more balanced over the whole field under peanut.

Due to a rising demand for food and consequently a pressure on agricultural land, further research on Arenosols concerning the best cultivation methods, such as the selection of appropriate crops, will become increasingly important. This is especially owing to a great area and population being affected by desertification and its negative impact on nature and human life. Thus, the implementation of avoidance measures is of utmost importance, especially for the realisation of the SDGs.

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