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Sustainable Decisions in Bio-economy

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Edited by

D. Bochtis, D. Aidonis, M. Lampridi, D. Kateris

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Sustainable Decisions in Bio-Economy

Conference Proceedings

Editors

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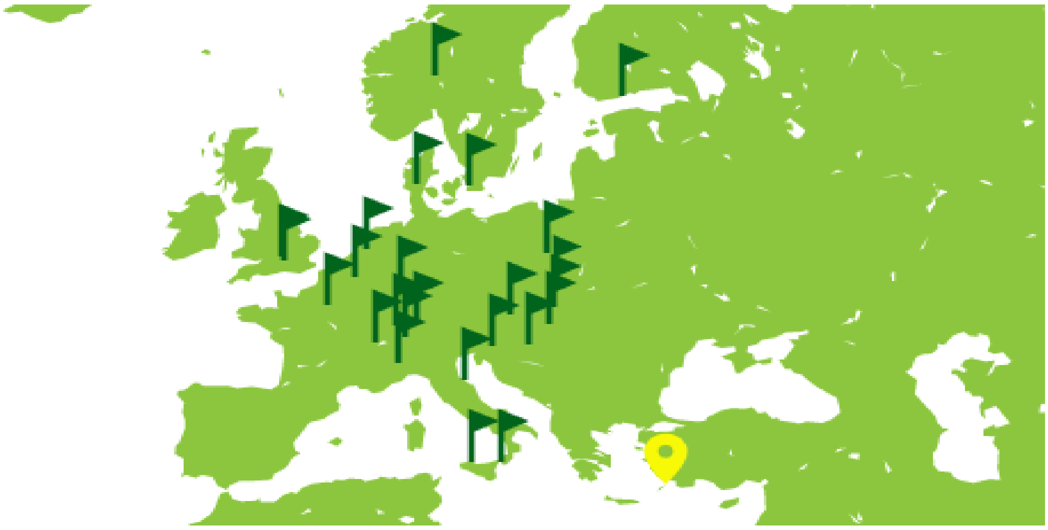

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Cross-cutting Themes
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Open Topics

Preface

Agricultural production has rapidly changed in the last decades following the need for intensification in order to meet the increasing food and agri-products demand. The evolution of agri-technologies, within the context of improving the efficiency of agricultural production, encourages the adoption of new methodologies and tools for the performance of agricultural tasks. Intelligent machines, autonomous vehicles, innovative sensing and actuating technologies, along with improved information and communication technologies have led to a complete restructuring of agricultural production with decision-making tools and practices now taking a prominent role in the agri-business.

As technology advances, agricultural production management practices are now called upon, to address the need for sustainability in the bio-economy. Hence, the focus also lays on broadening the knowledge on the development of decision-making tools and the promotion of practices and technologies that reduce the use of inputs, especially those that are harmful for humans and the environment, increase the efficiency of energy, water and land use and promote safe, and of high quality, agricultural products. Although these advanced features have been adequately described and analysed in general industrial production and management textbooks, the issue of sustainable decisions in the bio-economy needs to be viewed in a different, more spherical and integrated way.

The **CIOSTA & CIGR V International Conference,** with presence from 1950 and participants from 40 countries, is part of the action of the Commission **Internationale de l'Organisation Scientifique du Travail en Agriculture** (CIOSTA) and the **Commission of Agricultural and Biosystems Engineering – Section V: Systems management** (CIGR V). The conference focuses on research and innovation in the management of agricultural and forestry systems focusing on **Sustainable Decisions** in the field of **Bio-economy**.

These proceedings contain selected peer reviewed research papers accepted for publication at **XXXVIII CIOSTA & CIGR V International Conference** which was held in **Rhodes Island, Greece**, on **June 24-26, 2019**. In that light we would like to thank the authors and CIOSTA 2019 participants for their contribution to these proceedings. We would also like to thank the reviewers, members of the Scientific Committee, for ensuring the Proceedings quality as well as the invited keynote speakers Prof. Avital Bechar, and Prof. Simon Pearson for their inspired lectures.

The Editors,

Prof. Dionysis Bochtis	**Prof. Dimitrios Aidonis**	**Ph.D.C. Maria G. Lampridi**	**Dr. Dimitrios Kateris**
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AGROECOLOGICAL EFFICIENCY OF SITE-SPECIFIC FERTILISER APPLICATION IN THE NORTH-WEST OF THE RUSSIAN FEDERATION

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ABSTRACT

The high spatial soil variability is the natural feature of soil covering in the North-West region of the Russian Federation. This heterogeneity requires site-specific management at the field scale. The main objective of the presented research is to examine the effectiveness of site-specific fertiliser application by reference of specific features of the agro micro-landscape conditions. The field site is a 22-ha field located in Leningrad region. The soil was typical and gleyic sod-podzolic. The most important characteristic for the present research is the high spatial variability of soil properties. The introduced crop rotation was: potato – spring barley – perennial grasses of the first and second harvest year – winter wheat. Research factors were (1) control (no fertilisation); CvF - conventional fertiliser application: mineral fertilisers added annually according to conventional agriculture practice; SsF I - mineral fertilisers added annually according to soil properties; SsF II - in 2008 only potassium fertilisers were applied site-specifically to reduce spatial variability of potassium content. During the following years, the after-effect was observed and mineral fertilisers were applied uniformly; SsF III – mineral fertilisers added annually according to yield map data; (2) agro micro-landscapes (accumulative-eluvial, accumulative, eluvial and transite-accumulative). The average data of the five-year investigation show that the highest productivity without fertilisation was gained in the accumulative agro micro-landscape, and the lowest – in the eluvial agro micro-landscape. The highest yield of all investigated crops was harvested when potassium fertilisers had been applied site-specifically. In other cases, the yields were almost equal in conventional and site-specific fertilisation.

Keywords: spatial variability, yield, conventional fertilisation, site-specific fertilisation.

1. INTRODUCTION

One of the main factors for obtaining high crop yields is a rational fertiliser application. The significant achievements in IT-technologies at the turn of Millennium have made it possible not only to collect and process non-generalized status information about variability of soil and crop conditions but to use it for site-specific crop management (Lechner & Baumann, 2000). Precision farming technologies have adopted sequentially, with each providing a degree of marginal benefit to the farmer (Khanna 2001; Roberts et al., 2004). Soil properties differ greatly in their small-scale distribution. The high spatial soil variability is the natural feature of soil covering in the North-West region of the Russian Federation. This heterogeneity requires site-specific management at the field scale to avoid wasting resources, environmental pollution and decreasing soil fertility. For example,

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uniform nitrogen fertilisation within fields contributes to the global input of reactive nitrogen to terrestrial ecosystems, drainage water and the atmosphere (Galloway et al., 2003; Liu et al., 2010; Fowler et al., 2013). This research was done by Saint-Petersburg State Agrarian University in close cooperation with Agrophysical Research Institute. The main objective of the presented research is to examine the effectiveness of site-specific fertiliser application by reference of specific features of the agro micro-landscape conditions.

2. METHODOLOGY

Experimental part of the study was performed in field trials of Menkovskaya Research Station of Agrophysical Research Institute in 2008 – 2013. The introduced crop rotation was: potato (2008) – spring barley undersown with perennial grasses (2009) – perennial grasses of the first harvest year (a mixture of timothy with meadow fescue) (2010) – perennial grasses of the second harvest year (a mixture of timothy with meadow fescue) (2011) – winter wheat (2012). Crop varieties registered in the Russian Federation were investigated: potato Nevsky, spring barley Suzdalets, timothy Leningradskaya 204, meadow fescue Suydinskaya, winter wheat Inna. The field site is a 22-ha field located in Leningrad region, Gatchina district. The soil was typical and gleyic sod-podzolic developed on red moraine sandy loam (according to the USSR soil classification).

Soil agrochemical characteristics were as follows: pH_{KC1} (potentiometrically on 1 M KCl suspension) – 5.50, hydrolytic acidity (by Kappen method modified by CINAO) – 2.99 mg-eq. per 100 g of soil, total exchangeable basis (by Kappen method) – 15.50 mg-eq. per 100 g of soil, organic matter content (oxidizing the soil with potassium dichromate ($K_2Cr_2O_7$)) – 4.36%, the content of plant available phosphorus and potassium (by Kirsanov method modified by CINAO) – 434 and 197 mg kg-1 of soil, respectively.

The research factors were: factor A – agro micro-landscapes and factor B - fertilisation. To investigate the influence of agro micro-landscapes the key-site method was used. There were 4 key sites: accumulative-eluvial, accumulative, eluvial and transite-accumulative. The following fertiliser applications were used: C – control treatment: without fertilisers; CvF – conventional fertiliser application: mineral fertilisers added annually according to conventional agriculture practice; SsF I – the first site-specific fertiliser application: mineral fertilisers added annually according to soil properties; SsF II – the second site-specific fertiliser application: in 2008 only potassium fertilisers were applied site-specifically to reduce spatial variability of potassium content. During the following years, the after-effect was observed and mineral fertilisers were applied uniformly; SsF III – the third site-specific fertiliser application: mineral fertilisers added annually according to yield map data. Experimental data evaluation was done using two-factor analysis of variance by least significant difference (LSD_{05}).

Information about the weather was obtained from the Menkovskaya Research Station. Almost all vegetation periods had a higher temperature regime as compared to the long-term average. In the vegetation periods of 2008 – 2012 the precipitation was 1.6 – 2.6 times as high as the long-term average. In the vegetation periods of 2008 – 2012, excessive moisture was observed, and the hydrothermal coefficient (HTC) was 2.0 – 3.5.

The soil preparation was conventional for crops in the North-West region of the Russian Federation. All crops were harvested at the time of plant maturity and evaluated for yield. Registration plot area was 6000 sq. m; the experiment was carried out in fourfold replication. The yield of barley, perennial grasses and winter wheat was recalculated in t ha-1 at standard moisture and 100% purity. The yield of potato was recalculated in t ha-1 at natural moisture and 100% purity.

3. RESULTS

The most important characteristic for the present research is the high spatial variability of soil properties. Soil data were analyzed statistically for descriptive statistics such as mean, maximum, minimum and coefficient of variation (CV). The parameters based on descriptive statistics can be seen from table 1. It shows that the spatial variation of organic matter and plant available potassium is the largest and the coefficient of variation is 26 and 25%, respectively. The spatial variability of plant available phosphorus and exchange soil acidity is less and the coefficient of variation is 18 and 6%, respectively.

Table 1. The statistics value of soil parameters

Item	Minimum	Maximum	Mean	CV, %
Organic matter	1.70	7.54	4.36	26
pHKCl	4.30	6.90	5.50	6
Plant available phosphorus (P_2O_5), mg kg^{-1}	232	580	434	18
Plant available potassium (K_2O), mg kg^{-1}	76	360	197	25
Hydrolytic acidity, mg-eq. per 100 g of soil	2.99	0.84	4.82	23
Total exchangeable basis, mg-eq. per 100 g of soil	15.5	6.0	26.4	25

The factual fertiliser rates applied according to the scheme and the average annual productivity of crop rotation are presented in Table 2. The results presented in Table 2 show that all average data of the five-year investigation show that the highest productivity without fertilisation was gained in the accumulative-eluvial agro micro-landscape, and the lowest – in the eluvial agro micro-landscape. The highest yield of all investigated crops was harvested when potassium fertilisers had been applied site-specifically (SsF II). In other cases, the yields were almost equal in conventional and site-specific fertilisation.

Table 2. Average annual productivity of crop rotation depending on fertilisation and agro micro-landscape conditions

Agro micro-landscape Factor A	Fertilisation Factor B	Average annual fertiliser rates	Main product yield, t of grain units ha^{-1}	Yield increase	
				t ha^{-1}	%
Accumulative-eluvial	C	0	2.03	-	-
	CvF	$N_{94}P_{45}K_{63}$	3.77	1.74	85
	SsF I	$N_{107}K_{55}$	4.22	2.19	107
	SsF II	$N_{94}P_{45}K_{88}$	4.34	2.31	113
	SsF III	$N_{108}P_{53}K_{123}$	4.12	2.09	102
Accumulative	C	0	1.82	-	-
	CvF	$N_{94}P_{45}K_{63}$	4.11	2.29	127
	SsF I	$N_{98}K_{59}$	4.20	2.38	133
	SsF II	$N_{94}P_{45}K_{63}$	4.54	2.72	150
	SsF III	$N_{89}P_{44}K_{59}$	4.31	2.49	138
Eluvial	C	0	1.61	-	-
	CvF	$N_{94}P_{45}K_{63}$	3.66	2.05	127
	SsF I	$N_{104}K_{52}$	4.04	2.43	150
	SsF II	$N_{94}P_{45}K_{63}$	3.96	2.35	146
	SsF III	$N_{96}P_{45}K_{60}$	3.86	2.25	140
Transite-accumulative	C	0	1.95	-	-
	CvF	$N_{94}P_{45}K_{63}$	3.95	2.00	102
	SsF I	$N_{91}K_{51}$	4.01	2.06	106
	SsF II	$N_{94}P_{45}K_{93}$	4.41	2.46	126
	SsF III	$N_{96}P_{45}K_{67}$	4.07	2.12	108
LSD_{05} A				0.35	
LSD_{05} B				0.31	
LSD_{05} AB				*ns	

4. Discussion

According to the experimental results, the lowest potato tuber yields were harvested in accumulative and eluvial agro micro-landscapes. These yields fluctuated from 9.01 t ha^{-1} to 10.40 t ha^{-1}. Potato tuber yields with site-specific fertilisation according to soil properties were almost equal to conventional treatment. The highest potato tuber yield was achieved under site-specific potassium fertilisation. Potato tuber yield in the last mentioned treatment was 8 – 22% higher compared to conventional treatment.

Unfertilised barley produced significantly higher yields in the accumulative agro micro-landscape compared to other ones. The significant difference between conventional and site-specific fertilisation was only in accumulative-eluvial agro micro-landscape. The yield increase fluctuated from 0.57 t ha^{-1} to 1.17 t ha^{-1}.

In 2010 the highest perennial grasses hay yield without fertilisation were harvested in accumulative and accumulative-eluvial agro micro-landscapes because of their better nutrient and water status. The significant yield gain was harvested when mineral fertilisers had been applied according to the soil properties under the conditions of eluvial agro micro-landscape. In accumulative-eluvial agro micro-landscape fertilisation according to potassium content was effective as well.

The perennial grasses hay yields in 2011 were less than in 2010. It was because of gradual soil compaction till steady-state density. The yield gain was the lowest in eluvial agro micro-landscape. It is probably related to the large nitrogen leaching losses because of excessive precipitation.

According to the experimental results from 2012, the lowest winter wheat grain yield was obtained without fertilisers. In the current research conventional nitrogen fertiliser was significantly ($p < 0.05$) increasing winter wheat grain yield. All fertiliser applications used have a significant effect on winter wheat grain yield increase if compared to control. In the treatments with site-specific fertilisation winter wheat produced 0.40 – 1.31 t ha^{-1} higher yields in comparison with conventional fertilisation almost independently of agro micro-landscape conditions. Winter wheat produced significant yield gain with the above mentioned treatments except the transite-accumulative agro micro-landscape.

5. Conclusions

All the investigated factors (agro micro-landscapes and fertilisers) influenced the crop yields. Conventional fertilisation has significant impact on the crop productivity. In a gleyic sod-podzolic soil, crop fertilisation at a N94P45K63 fertiliser rate resulted in a yield increase by 85 – 127%. Site-specific fertilisation according to soil properties increases the crop productivity. The highest yield increase (113 – 150%) was achieved in the treatment site-specifically fertilised by potassium in 2008. Compared to conventional fertilisation, the yield under SsF II was 8 – 15% higher. The main advantage of site-specific fertiliser application is not only to increase the yield but to reduce the spatial variability of soil properties. According to our research, the coefficient of variation of plant available potassium was reduced from 25 to 9%. The agro micro-landscape conditions influence significantly on crop yields and crop rotation productivity. The rates of fertilisers should be change according to the micro-landscape conditions.

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EFFECT OF EXTRUDED PLANTAIN PEEL-BASED FISH FEED DIET ON GROWTH PERFORMANCE AND NUTRIENT UTILIZATION OF CATFISH (CLARIAS GARIEPINUS)

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ABSTRACT

The increasing cost of fish feed production has led to the need to search for alternative and non-conventional raw materials, including waste. Indiscriminate discarding of plantain peel has led to environmental challenges. A possible way to manage this waste could be to produce fish feed through extrusion cooking. Plantain peel flour produced by drying and grinding fresh peel obtained from a processing plant and was used to replace wheat bran at different levels (0, 5, 10, 15 and 20%) to produce a formulated balanced diet fish feed. The extruded feed was used daily at 5% body weight for eight weeks for the feeding trial. Growth performance parameters (Total Weight Gain (TWG) and Specific Growth Rate (SGR)) and nutrient use indices (Feed Conversion Ratio (FCR) and Feed Efficiency (FE)) were assessed. Data were analyzed using ANOVA at $\alpha_{0.05}$, for the sensitivity analysis. The formulated fish feed with 15% plantain peel showed the highest weight gain and best FCR. For the growth parameters, a significant variation of $p < 0.05$ was observed. Fish fed with 5% and 15%% plantain peel had the highest survival ratio. Significant variation was observed in the apparent digestibility of the control and experimental feed. Plantain peel could be used to formulate extruded fish feed to reduce production cost and environmental nuisance.

Keywords: fish feed, plantain peel, extrusion, mortality, growth.

1. INTRODUCTION

Aquaculture industries and those operating in the foodservice are increasingly looking for ways to make the production system more sustainable (Smith et al., 2010). These large corporate firms are not only looking at the way that fish are raised. They also have an increased interest in the production cost, hence how sustainable the feed ingredients really are and which changes can be made. By looking at the alternative feed sources, sustainability gains can be made that have a significant and long-term effect on parameters such as growth, feed conversion ratio and its efficiency amongst others. These efforts, geared towards reducing the production cost, will make fish farming attractive to both private and commercial investors and ultimately boost fish production. One of such is the utilization of plantain peel for catfish feed production (Lawal et al., 2014).

Plantain by-products from the plantain chips industry are considered to be waste, although they can be used as a feed ingredient. The peel is a cheap source of crude protein, crude fibre, phosphorous, unsaturated fatty acids and essential amino acids (Wolfe et al., 2003). An effective replacer of wheat bran in the fish diet added benefit that reduces feed costs (Ajasin et al., 2014). Replacing part of the wheat bran consumption by locally generated plantain peel products seems to be a promising way to

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reduce dependency on wheat products since most of the wheat were imported from overseas. Replacing wheat bran by plantain peel is worthwhile and a resource that will stay around for some time. A possible way of managing this waste could be in the production of fish feed through extrusion cooking.

Extrusion cooking has become one of the most popular technologies in food processing. It is a process by which moistened, expansible starchy and proteinous materials are plasticized and cooked in a tube by combination of moisture, pressure, temperature and mechanical shear (Singh et al., 2007). Extrusion cooking principles have been widely applied for the retention of nutrients, and adequate heat treatment against anti-nutritional factors and production of new products (Anuonye et al., 2009). In a study by Agbabiaka et al. (2013), there was a development to replace plantain peel with maize in pelletized fish feed, the technology has limitation in the availability of the nutrients and the quantity required to substitute for maize. Therefore, this study was aimed at evaluating the effect of extruded plantain peel aqua feed and its performance on the growth and digestibility by catfish (Clarias gariepinus).

2. MATERIALS AND METHODS

2.1 Sample preparation

Plantain peels was collected from processing unit of Product Development Programme, National Horticultural Research Institute (NIHORT), Jericho, Ibadan, Oyo State, Nigeria. The peel was dried at 60 ± 1^{o}C using a bed drier (Model Fexod D52, Nigeria) to about 10% moisture, milled to 0.2 mm particle size while the proximate analysis was determined using Association of Official Analytical Chemists (AOAC) methods (2005).

2.2 Feed formulation

Plantain peel flour was mixed with other feed ingredients at varying levels. Five nutritionally isocaloric ingredient feed blends were formulated to an isonitrogenous net target protein of 38% wet basin (wb), using four levels of plantain peel inclusion, namely 5, 10, 15 and 20%, while 0% level was used as control feed (Table 1).

Table 1: Gross Composition (g) of Experimental Diets

Feed ingredients	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5
Groundnut cake	16	16	18	20	22
Soymeal	23.7	23.7	21.7	19.7	17.7
Fishmeal	22	22	22	22	22
Wheat bran	25	20	15	10	5
Corn flour	5	5	5	5	5
Cassava flour	5	5	5	5	5
Plantain peel	0	5	10	15	20
DPC	0.5	0.5	0.5	0.5	0.5
Salt	0.5	0.5	0.5	0.5	0.5
Lysine	0.1	0.1	0.1	0.1	0.1
Methionine	0.1	0.1	0.1	0.1	0.1
Vitamin C	0.1	0.1	0.1	0.1	0.1
Fish oil	1.5	1.5	1.5	1.5	1.5
Premix	0.5	0.5	0.5	0.5	0.5
Total	100	100	100	100	100

The feed mash was extruded with a single screw extruder (Model Fexod S22C, Nigeria) and dried at 60 ± 1°C in a fluidized bed drier (Model Fexod D52, Nigeria) and packaged in a polyethene bag for further use.

2.3 Experimental fish and design

One hundred and fifty African catfish fingerlings, with an average weight of 2.5 g were collected from the Fish Farm, Department of Aquaculture and Fisheries Management, University of Ibadan. They were acclimated for seven days and fed with control diet. Subsequently, they were randomly assigned to the five-treatment diet at 30 fish per treatment in a plastic tank. Each treatment was replicated thrice in a randomized design having ten fish per replicate. The extruded feed was used for feeding trial at 5% body weight daily for eight weeks. The water was changed daily by siphoning.

2.4 Data collection and statistical analysis

The experimental fingerlings in each tank were weighed at the beginning of the experiment and weekly using a digital weighing balance (model Salter 1260SVDR, UK). Data on growth performance; Total Weight Gain (TWG), Total Growth Rate (TGR) and Specific Growth Rate (SGR), Feed Conversion Ratio (FCR), Feed Efficiency (FE) and nutrient utilization; Apparent Digestibility Coefficient (ADC) were collected using Morais et al (2001) methods. Data were analyzed using ANOVA at $\alpha_{0.05}$, while response surface methodology was employed for the sensitivity analysis using Design Expert 11.

3. RESULTS

The composition of the plantain peel used for the study shows the percentage of crude protein (5.38%), crude fiber (9.67%), crude fat (0.57%), moisture content (9.7%) and ash (4.0%). The result obtained revealed that plantain peel has higher content of crude fibre, ash, carbohydrate and appreciable amount of protein compared to wheat bran. Hence it was used to replace wheat bran in the fish feed diets. The study showed that fish fed 15% plantain peel inclusion had the highest TGR and SGR followed by the control (diet 1). Significant variation ($p<0.05$) in the TWG and SGR was observed among the diets (Table 2).

Table 2: Growth Performance Indices of Catfish fed the control and experimental feed

Response/Model	F-value	P-value	R^2	Std deviation
Total Weight gain	15.84	0.0006*	0.8407	0.64
Specific growth rate	16.82	0.0005*	0.8487	0.17
Feed conversion ratio	4.67	0.312	0.6087	0.25
Feed efficiency	3.70	0.0553	0.5522	4.57
Survival ratio	2.70	0.1082	0.4739	7.76

*- Significantly different

As depicted on Fig. 1, TGR decreased from 40.23 g of plantain peel-fed fish to 36.81 g (fed with 5% peel) and then increased until it reached its maximum at 41.06 g (fed with 15% peel). The same trend was observed for SGR (Fig. 2); maximum SGR was observed for fish fed 15% followed by the control. The FCR increased from 1.80 (without peel) to 2.07 (taken with 5% peel), followed by a decrease to 1.78 in a 15% fed plantain peel (Fig. 3). The FCR did not differ significantly at ($p>0.05$), but it was found that fish fed with 15% plantain peel consume enough feed and nutrient utilization than other diets, which increases weight gain. Similarly, FE of the control and experimental feed were not significantly different ($p>0.05$), however, 15% plantain peel had highest FE (Fig. 4). The survival ratio of the control and experimental feed were not significantly different ($p>0.05$). Highest survival ratio of 100% was observed at 20 % plantain peel inclusion, while 15% had the least of 80% survival ratio (Fig. 5).

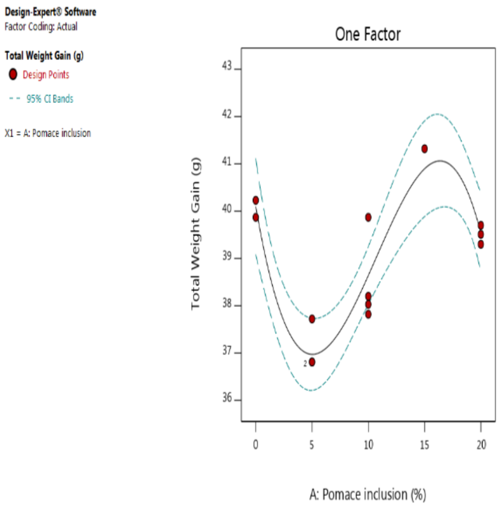

Figure 1: Total weight gain of fish fed control and experimental feed

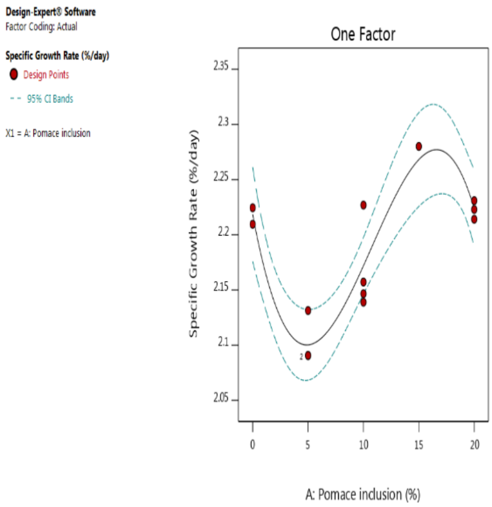

Figure 2: Specific growth rate of fish fed control and experimental feed

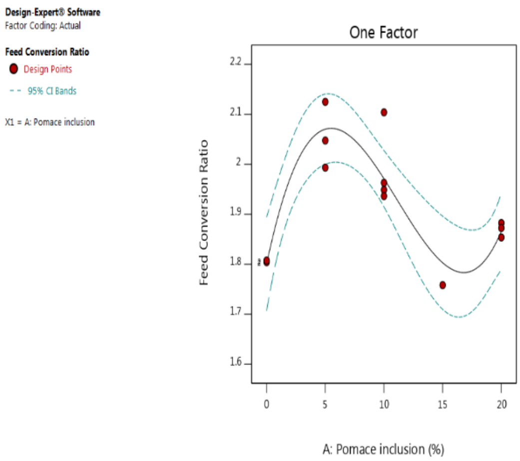

Figure 3:Feed Conversion ratio of control and experimental feed

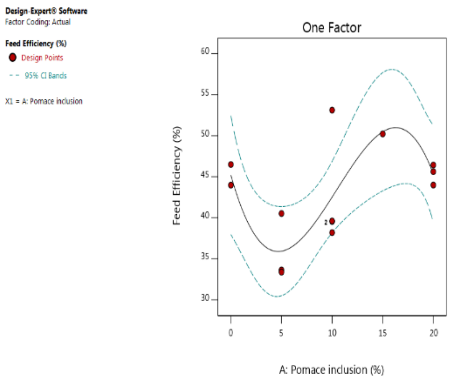

Figure 4: Feed efficiency of control and experimental feed

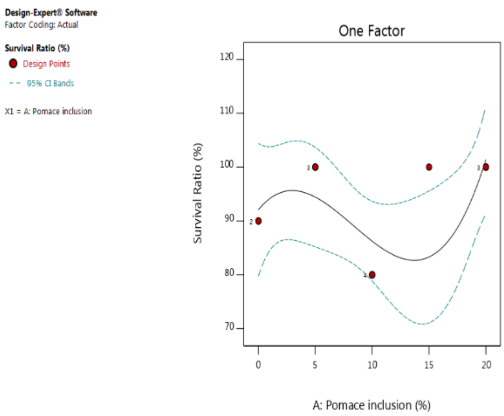

Figure 5:Survival ratio of fish fed control and

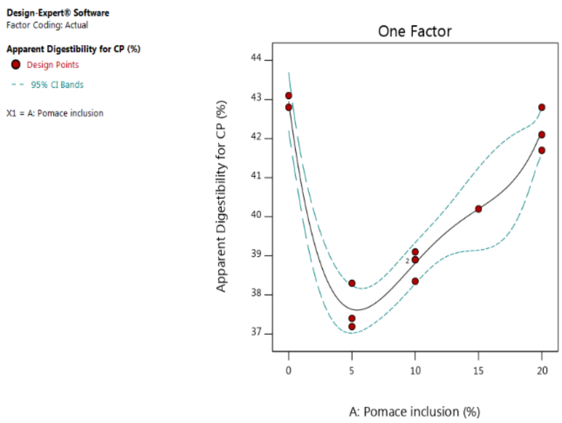

Figure 6: Apparent digestibility of fish fed

experimental feed	control and experimental feed

Significant variation was observed in the apparent digestibility of the control and experimental diet (Table 3). Apparent digestibility of protein decreased from 42.8% to 37.2% (Fig. 6).

Table 3: Digestibility parameters of control and experimental diets

ADC	% replacement					R^2	P-value
	0	5	10	15	20		
Protein	42.8	41	40.2	37.2	38.9	0.9595	< 0.0001
Fat	7.92	7.81	7.65	7.22	7.51	0.9573	< 0.0001
Digestible Energy (KJ/g)	20.4	11.8	12.30	10.6	16.17	0.9962	< 0.0001

4. DISCUSSION

The observation of the weight gain phenomenon with the plantain peel inclusion in the diets were in agreement of the findings of Agbabiaka et al. (2013) of increased weight gain in peel supplemented for maize in pelletized catfish feed. The decrease in weight gain from control up to 10% plantain peel inclusion could be a result of high fibre level which accumulates to increase cell wall materials and non-soluble polysaccharides, which invariably limit the rate of digestion and nutrient absorption (Aderolu and Oyedokun, 2009). The increase at 15% could be due to optimum energy to protein ratios of the feed which encourages more feed intake and growth of the fish (Lemos et al., 2014) and also the presence of amylase and cellulase in catfish which were responsible for the breakdown of cell wall material in plantain peels couple with the grinding effects of the vomerine teeth, characteristics of Clariid catfishes which exposes the cell wall surface area to digestion (Agbabiaka et al., 2013). The observed cubic replica for the feed utilization (Fig. 3) indicated a high FCR at 5 and 20% peel inclusion which could probably due to poor palatability of the feed. This was substantiated by Lawal et al. (2014) that the presence of anti-nutritional factors which include hydrogen cyanide, saponins, oxalate and phytate in plantain and banana peel affects palatability. The digestibility parameters of the catfish established a high regression values (R^2) between 0.95-0.99 indicating that the peel inclusion level make a change in digestion of the feed. Although the inclusion levels of plantain peel agreed with the digestibility of the protein, the extrusion cooking method applied for the processing of the diet could contribute the high digestibility coefficient values obtained. The ADC of the control diet was significantly ($p<0.05$) higher than other treatments (Table 3). The decreased crude protein digestibility of the diets established in this study was slightly different. This may be due to presence of enzyme inhibitors in the diet and the protein chemically unavailable (Oujifard et al., 2012).

5. CONCLUSION

Plantain peel was successfully used to replace wheat bran in extruded fish feed. The best growth rates were achieved with a 15% inclusion of plantain peel, while the use of nutrients was also noticeable. It can be concluded that plantain peel could be used to formulate extruded fish feed for optimum growth, to reduce production cost and its environmental nuisance.

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EFFECT OF EXTRUSION CONDITIONS ON THE THROUGHPUT OF EXTRUDER FOR THE PRODUCTION OF PINEAPPLE POMACE BASED FISH FEED

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ABSTRACT

Pineapple pomace based extrudates could serve as fish feed with significant health benefits to the fish if supplemented with adequate amounts of other ingredients and mineral-vitamin blends. Pomace is generally disposed during production in juice processing industries and has valuable use in fish production. Response surface methodology was used to examine the extrusion processing effect parameters such as feeding rate (1.28, 1.44 and 1.60 kg min^{-1}), screw speed (305, 355 and 405 rpm), barrel temperature (60, 80 , 100 and 120°C) cutting speed (1300, 1400 and 1500 rpm) and open die hole (50, 75 and 100%) in relation to moisture content of the mash (16, 19 and 22%) with increased pomace inclusion (5-20%) on the throughput of a single screw extruder. Throughput significantly decreased with increased inclusion of pineapple pomace, moisture content, die cutting speed, open surface hole and reduced screw speed. The extruder worked optimally to achieve a throughput of 46.82 kg hr^{-1} at feeding speed (1.60 kg min^{-1}), screw speed (405 rpm), moisture (16.0%), temperature (120°C), cutting speed (1400 rpm), pomace inclusion (5.0%) and open surface (100%). The use of pineapple pomace to produce fish feed and extruder performance is a novel approach with potential to reduce environmental nuisance.

Keywords: Pomace, extrusion, single screw, response surface methodology, feed.

1. INTRODUCTION

Rising demand for quality protein for human consumption can be fulfilled by sustainable aquaculture. However, the industry is experiencing a decline as a result of high production costs caused by high feed costs**.** In order to effectively free aquatic ecosystems, fish farming should be more sustainable, such as an alternative fish feed, without shortage and expensive ingredients (Smith et al., 2010). However, prices for conventional ingredients are on the rise and pose a risk to the environment. Therefore, the future of aquaculture will depend on how well it overcomes this challenge through a sustainable bio-based economy, and incorporation of biological (Bennich and Belyazid, 2017). One of the identified materials that have great potential as a feed source is pineapple pomace (Devi et al., 2016). However, such new concepts must be technically and economically viable in order to succeed in the long term.

The pomace (35% of whole fruit) produced after the processing of pineapple has been causing nuisance to the environment as a result of inappropriate disposal method (Bocco et al., 1998). About 60-75 tons per day of the pomace is generated in a fruit processing plant during one season and 10 to 15 tons per

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day is generated off-season with cost of disposing the waste estimated to about 237US$ per day (Oduntan and Bamgboye, 2015). Therefore, a way of reducing the nuisance and environmental problems is in its conversion to useful products. This is expected to ameliorate the cost of disposal while adding economic value to the pomace. One promising way of its utilization is in the production of feed for animals. Heuze et al. (2013) reported that pomace has high nutrient digestibility effect in animal models. However, the primary challenges in the aquaculture sector are the process methodology, the poor functionality of the mash, the availability of various anti-nutritional factors and lack of important nutrients. One of the effective conventional technologies of doling out the pineapple pomace into animal feed is extrusion cooking process.

Extrusion is a processing operation that utilizes high temperature, pressure and shear to produce highly-expanded low-density products with unique texture properties, feed conversion, sterilization, palatability, ensuring the availability of nutrients and develop new products (Pardeshi and Chattopadhyay, 2014). Extrusion also leads to extrudates with high durability and water stability, and the process can be adapted to produce floating feed that is more suitable to aquatic species and allows direct determination of feed consumption (Lundblad et al., 2012). It is important to study the extrusion cooking process for optimum conditions for the production of pineapple pomace. The use of a single screw extruder requires the minimization of unnecessary deformation, energy usage, and improved product quality. The throughput of an extruder is directly linked to production capacity (Bereaux et al., 2009). In this work, throughput of the extruder was evaluated at different processing factors. Simple models were also applied in order to predict machine throughput from process parameters using response surface methodology.

2. METHODOLOGY

2.1 Sample Preparation

Wet pineapple pomace sample was obtained from a juice processing plant in Ibadan, Nigeria (Funman Agricultural Products Ind. Ltd, Moor Plantation). The pineapple pomace was dried in a fluidized bed dryer (AS 230, Fexod, Nigeria) at temperature of 65°C and air velocity of 5.0 m s^{-1} in a forced convection thin layer dryer with the loading thickness between 10 - 15 mm (Hosseini Ghaboos et al., 2016). The dried samples were ground to powder through a 0.2 mm screen plate in a disc mill (AS 230, Fexod, Nigeria).

2.2 Feed Blend Formulation

Pomace flour was used to replace wheat bran at various levels (5, 10, 15 and 20%) to produce a formulated, balanced diet catfish feed. Nutrient composition was based on the current data available for feeding catfish (Njieassam, 2016). The formulated feed components (Table 1) were then ground and sieved through a 0.2 mm diameter screen (DS 200, Fedek, Nigeria) to obtain a uniform particle size distribution (Sacilik and Unal., 2005). The composition was mixed by adding water to each formulated blend to increase the initial moisture content (12%) to 16, 19 and 22% for 10 minutes (Oduntan and Bamgboye, 2015) in a batch mixer (Fexod AS 170, Nigeria).

Table 1: Ingredient components in the prepared feed blends

Feed ingredients	Mass of ingredients (g/100g)				
	Control	Blend 1	Blend 2	Blend 3	Blend 4
Groundnut Cake	16	16	18	20	22
Soya Meal	23.7	23.7	21.7	19.7	17.9
Fish Meal (72%)	22	22	22	22	22
Wheat bran	25	20	15	10	5

Corn Flour	5	5	5	5	5
Cassava Flour	5	5	5	5	5
Pineapple Pomace	0	5	10	15	20
DPC	0.5	0.5	0.5	0.5	0.5
Salt	0.5	0.5	0.5	0.5	0.5
Lysine	0.1	0.1	0.1	0.1	0.1
Met	0.1	0.1	0.1	0.1	0.1
Vitamin C	0.1	0.1	0.1	0.1	0.1
Fish oil	1.5	1.5	1.5	1.5	1.5
Premix	0.5	0.5	0.5	0.5	0.5
TOTAL	100	100	100	100	100

2.2 Extrusion processing

Extrusion cooking was performed using a single-screw extruder (Fexod S22C, Nigeria) powered by a 5.15 kW electric motor. The extruder screw speed was monitored with the use of variable transformer (Milan, Italy) and photo/contact tachometer (Taiwan) to achieve the speed range of 0 to 409 rpm. However, the practical ranges of the feeding rate (1.28, 1.44 and 1.60 kg min^{-1}), screw speed (305, 355 and 405 rpm), barrel temperatures (60, 80 , 100 and 120°C) cutting speeds (1300, 1400 and 1500 rpm) and open die hole (50, 75 and 100%) in relation to moisture content of the mash (16, 19 and 22%) with increased pomace inclusion (5-20%) were taken into account in the experimental design (Oduntan and Bamgboye, 2015). The die head was equipped with a probe to monitor the temperature at the center of the product flow. The die had circular holes of 5 mm with a length of 10 mm (L/D of 2.0). Open surface of the die was modified by closing some of the 8 holes on the die. The extrudates were cut at the die exit with three hard knife blades. The products were dried in a fluidized bed (Fexod AS 230, Nigeria) at 85^{o}C. Samples were immediately transferred to thick polyethylene bags and stored at room temperature for further use.

2.3 Measurement of Extruder performance (Throughput)

The throughput of a single-screw extruder is based on the flow of resistance generated by the rotation of the screw and the pressure generated as a result of the constraint of the die. The extrusion throughput was calculated using equation (1) (Bereaux et al., 2009)

$$MFR = M_p/T \qquad (1)$$

where: M_p– average mass of the extrudates collected after extrusion (kg); T– extrusion time (h).

2.4 Statistical analysis

Data were analysed using ANOVA at $\alpha_{0.05}$, while response surface methodology was employed for the sensitivity analysis with the statistical software Design-Expert 11.

3. RESULTS

The throughput of the machine was in the range of 27.99 to 53.58 kgh^{-1}, with the maximum fraction to a minimum of 1.92. "F value adjustment" of 7.14 means the absence of a suitable fit. An F value of 2.80 and R^2 value of 0.9074 can be used to predict the levels of the responses of each factor. The model coefficients of feeding rate (x_1), temperature (x_4) and open surface die (x_7) were positive, indicating that the throughput increased as the factors increased (Equation 2). Among the independent parameters, the pomace inclusion index was significant. A negative coefficient of screw speed (x_2), moisture content (x_3), cutting speed (x_5) and pomace inclusion rate (x_6), indicated a decrease in the throughput as the factor values increased.

The Predictive model for throughput using coded variables is:

$$Y_{THR}= 44.90+1.13 x_1+3.21 x_2+0.46 x_3+0.35x_4-1.12 x_5-3.86x_6+2.89 x_7-0.17 x_1x_2+0.10 x_1x_3-0.35 x_1x_4+0.61 x_1x_5+1.51x_1x_6+1.14x_1x_7+0.35 x_2x_3+1.05 x_2x_4+0.43x_2x_5+2.89x_2x_6-0.47 x_2x_7-0.15x_3x_4+1.20x_3x_5+1.39 x_3x_6-2.53x_3x_7-1.92x_4x_5-0.69x_4x_6+0.45x_4x_7-1.61x_5x_6+0.39 x_5x_7+1.69x_6x_7-0.67x_1^2+2.39x_2^2+1.65 x_3^2-2.41x_4^2+0.58x_5^2-0.11x_6^2-0.96x_7^2 \quad (2)$$

4. DISCUSSION

Analysis of variance showed that the efficiency was significantly based on the linear conditions of extruder screw speed [(SS, $p < 0.05$)], pomace inclusion rate [(PI, $p < 0.05$)] and the open die surface [(OD, $p < 0.05$)] and the screw speed-pomace of inclusion interactions [(SS-PI, $p < 0.05$)]; moisture content-open die surface [(MC-OD, $p<0.05$)]. The pomace inclusion rate affected the throughput, while the temperature, feed rate and cutting speed did not have significant effect on the throughput.

The perturbation chart as shown in Fig. 1 shows the effect of individual factor on throughput. The throughput decreases from 44.76 to 40.93 kg hr^{-1} as the pomace inclusion rate increases from the zero point to the right. Similarly, a decrease in the throughput was observed with respect to the temperature (44.76-42.85 kg hr^{-1}) and cutting speed (44.76-44.36 kg hr^{-1}), which increase during the experiments. On the other hand, the machine's throughput increases sharply from reference point of 44.76 to 50.48 kg hr^{-1} as the screw speed increases. It was observed that the rate of feeding the extruder was low for all runs. This may be due to the design of screw configuration towards the use of pineapple pomace.

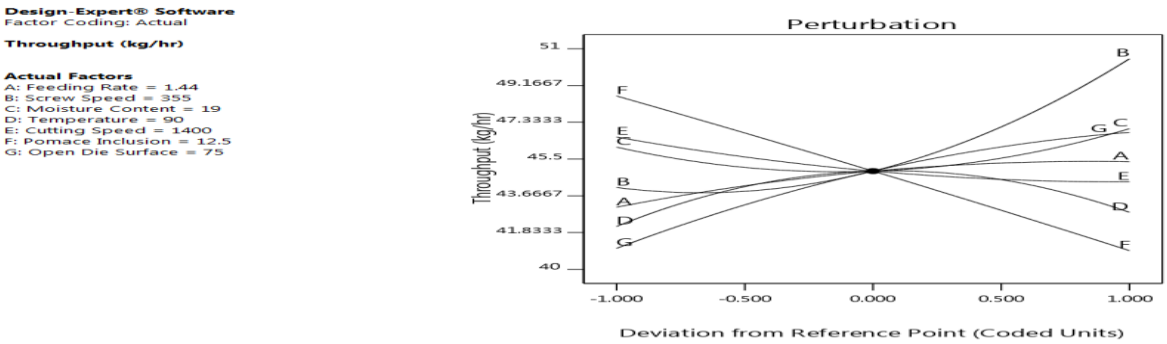

Fig. 1: A perturbation plan for machine Throughput

The effects of the interaction between the variables (pomace and screw speed) for the throughput are shown in Fig. 2. As the screw speed increases to the maximum value with low pomace inclusion, high values of the throughput were recorded. However, with the higher pomace and the minimum operating speed of the screw, the throughput decreases. Therefore, it appears that the throughput in a single-screw extruder depends on the resistance flow generated by the rotation of the screw and the pressure generated as a result of the restraint on the die. Tiwari and Jha, (2017) reported that the flow of resistance during extrusion processes is proportional to the screw speed. In addition, higher screw speeds resulted in higher throughput because greater feed transfer power was required along the extruder barrel (Rosentrater et al., 2009; Oduntan et al., 2014).

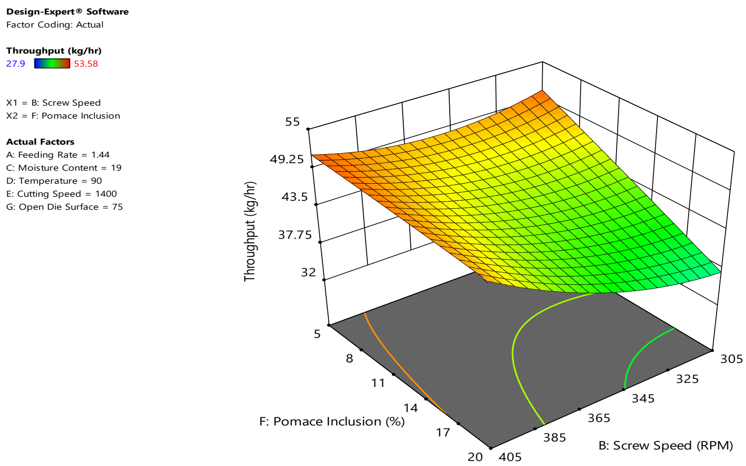

Fig. 2: Effect of pomace inclusion and screw speed on throughput

Fig. 3 shows that as the moisture level increases and the number of open die surfaces increases, the throughput increases. At the maximum openings of the die with the lowest moisture content, the highest throughput was observed. A similar phenomenon was observed by Fallahi et al., 2013 on the influence of moisture content on throughput. It was noticed that the increase in the moisture content in the mash caused a decrease in the throughput with the highest (100%) opening of the number of die holes. Chevanan et al. (2008) and Oduntan et al. (2014) reported similar capacity results with respect to moisture content variations.

The optimal conditions for pineapple pomace based fish feed specified limits, was obtained at a feeding rate of 1.12 kg min^{-1}; screw speed, 305rpm; moisture, 19.06%; temperature, 60°C; cutting speed, 1500 rpm; pomace inclusion rate, 5% and open surface die, 64.84% with a desirability of 0.67. At these optimised conditions, a predicted throughput was 46.82 kg hr^{-1}.

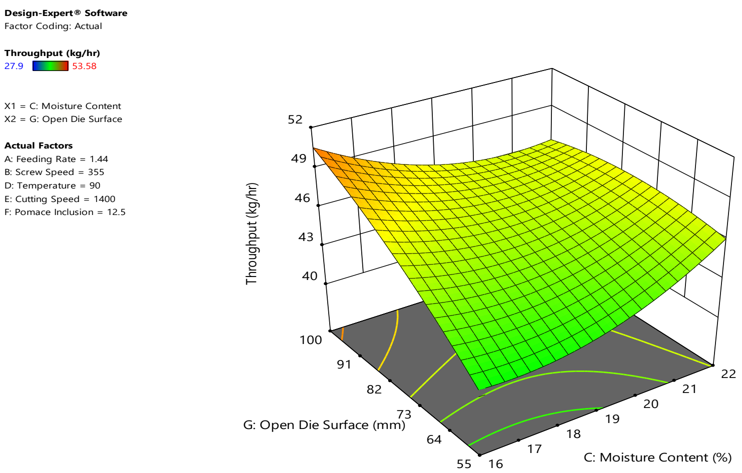

Fig. 3: Effect of open surface die (5mm) and moisture content on throughput

5.Conclusion

Extrusion process is attractive options for converting pineapple pomace into useful products such as fish feed with potential to reduce nuisance to the environment. The result shows that the screw speed, pomace inclusion speed and open die surface were extrusion variables that were found to affect the performance of the extruder. Understanding the effect of process variables with the use of waste on quality parameters of fish feed extrudates is important to facilitate industrial application of this technology.

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PREDICTION OF THE LOCAL AIR EXCHANGE RATE IN ANIMAL OCCUPIED ZONES OF A NATURALLY VENTILATED BARN

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ABSTRACT

The air exchange rate is an important parameter in order to evaluate the gas emission of naturally ventilated barns. At the same time, understanding the flow inside such barns helps to evaluate the comfort of the animals inside. In this context, the local air exchange rate in sub volumes of the barn (i.e. individual animal occupied zones) is far more interesting than the total air exchange rate. Yet even the total air exchange rate is difficult to assess mainly because of fluctuating influence stimuli such as wind (speed and direction), temperature, barn geometry etc.

One objective of the BELUVA project, financed by the German Research Foundation, is to address those influences and derive a parametric function for local air exchange rates. The function will further permit to answer questions associated with precision livestock farming. For example, for a given length/width ratio of a barn and a given inflow speed and angle, in which animal occupied zones a supporting mechanical ventilation must be switch on.

The present study has been carried out in order to evaluate the impact of incident wind angle and barn's length/width ratio on the local air exchange rate in animal occupied zones of barns. Beforehand the numerical model has been validated with measurements done inside a boundary layer wind tunnel with a down sized 1/100 barn. Three different incident wind angles (0°, 45° and 90°) and three different ratios of barn's length (L) /barn's width (W) (L/W=2,3,4) have been considered.

The results of this simplified model show that, while the barn's overall air exchange rate is independent of the length to width ratio, the ones for animal occupied zones inside the barn are not. The local air exchange rate depends strongly on the position inside the barn and the velocity incident angle.

A model extension towards a full-scale building with surroundings and including the effects of animals as obstacles and heat sources is on-going in order to further increase the accuracy of the predicted local air exchange rates.

Keywords*:* air exchange rate, computational fluid dynamics (cfd) simulation, model validation, animal occupied zone***.***

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1. Introduction

Recently applying computational fluid dynamics (cfd) simulations in order to study and analyze barn flow has become a common trend. Many numerical and experimental investigations on the effect of barn's geometrical design on the flow in and around naturally ventilated barns (NVB) have been done. For example, Saha et al. (2014) analyzed numerically the influence of different opening combinations on the flow inside the NVB. The author found out that the air exchange rate (AER) for the different configurations can change from 1.75 to 3 when compared to the standard configuration. Here however, the individual animal occupied zones (AOZ) were not been taken into account and the wind direction has been unchanged. Similar recent studies were done by Qianying (2017) and Gebremedhin (2004).

Another interesting, yet unexplored geometrical parameter is the length/width ratio of the barn. Indeed in Germany, barns have a typical geometry consisting of two lines of animal zones facing each other and separated by a way in the middle, in which the feed is provided ad libitum. Depending on the number of cows, those lines can get relatively long, i.e. there are high L/W ratios. In accordance with the German Federal ministry of food and agriculture (BMEL), barns are classed per number of animals and there is a recommendation of the place needed for one cow depending on body size. A survey conducted by the same ministry from 2007 to 2016 shows that even if the number of handled cattle in barns has remained relatively constant, the number of barns handling at least 100 cattle and more has increased from 22.4 % (corresponding to 63.2 % of the cattle in Germany in 2007) to 31.3 % (corresponding to 75.2 % of the cattle in Germany in 2016). The barns handling more than 200 cattle have doubled. One can conclude that in recent years, barns' size has been growing. Therefore for this study, we choose L/W = 2, 3 and 4 as representative values and a good compromise to keep the computational time reasonable.

2. Validation

2.1 Atmospheric boundary layer

A preliminary study in a completely empty domain was conducted to make sure that the atmospheric boundary layer stays unchanged along the domain. Another goal was to find out the roughness corresponding to the experimental setup, to be able to implement it in the simulation. According to this roughness height, the corresponding wall functions to calculate the velocity at the wall are used in Ansys Fluent. The roughness found for the simulations is k_S=0.0065 mm. The atmospheric boundary layer profile follows the corresponding equation given in Durbin et al., 2001 and Blocken et al., 2007:

$$U(y) = U_{ref} \times \frac{\ln\left(\frac{y}{y_0}\right)}{\ln\left(\frac{y_{ref}}{y_0}\right)}$$

In Ansys Fluent the roughness is defined as:

$$k_s = \frac{9.793\, y_0}{C_s}$$

Where *U(y)* is the wind velocity at the height *y*, U_{ref} a reference velocity at a reference height y_{ref} and C_S a roughness constant with a standard value of 0.5 (Blocken et al., 2007).

2.2 Model set up and grid convergence study

The barn was placed in the middle of an empty domain. *L* is the characteristic length, *H* is the characteristic height of the barn, 4 *L* is the distance from barn to domain's inlet, 6 *L* is the distance to the domain's outlet, 10 *H* to the top and 5 *H* to the sides. A mesh refinement box around the barn was also included according to Fluent recommendations (Lanfrit, 2005).

A grid convergence study was conducted in order to find the mesh that allows a reduced computing time while ensuring the required precision. The domain mesh was a combination of a structured (quadrilateral) and an unstructured (tetrahedral) mesh. The mesh was finer within the refinement box with the smallest cells and growing gradually towards the domain boundaries with the biggest cells. The finest mesh with 1 mm cell size for the barn was the reference mesh. The grid convergence study was conducted in 2.5 *D*, which means that the domain has been cut in the middle in the flow direction with 1 mm width. In doing so, the cells numbers and thus the computing times are considerably reduced while keeping the main regions of interest sufficiently resolved. This provides fast simulations (10 to 30 min) and accurate results of the study. The velocity profiles in the barn's middle from meshes with bigger cell size are compared with the reference mesh (1 mm). The resulting discrepancies are shown in Fig. 1. The discrepancies are relatively small (1 %) and approximately constant up to the cell size of 4 mm and then increase. Therefore a 4 mm cell size was chosen for the study. The cell number for the corresponding 3D case is around 6 million cells.

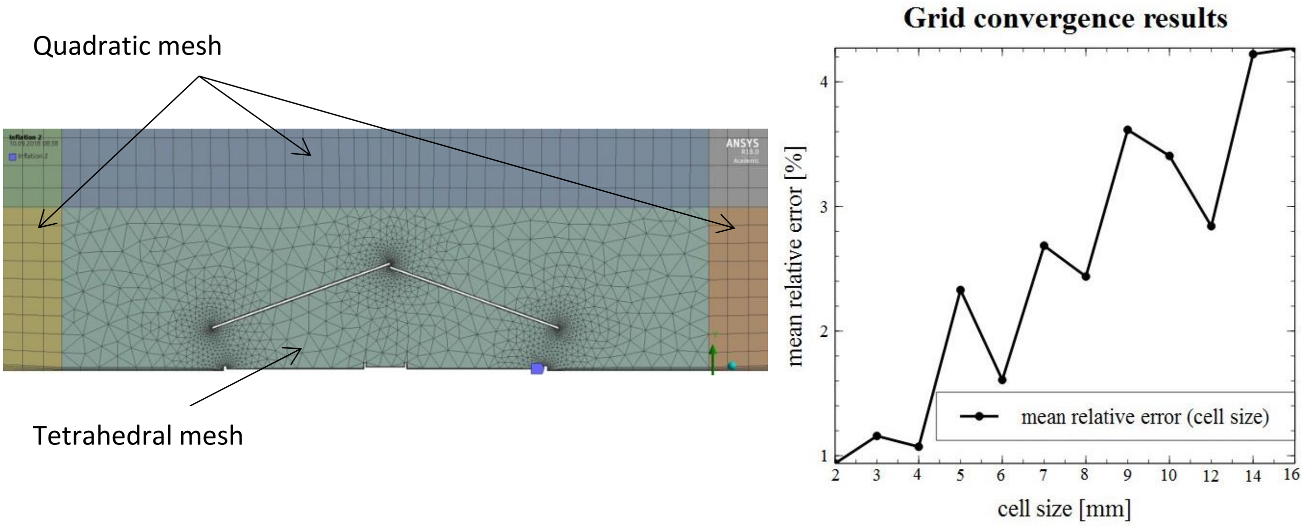

Figure 1. Left: Hybrid mesh 2.5D, Right: Grid convergence results

2.3 Model validation results

In the Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB) wind tunnel measurements were carried out in order to determine the velocity profiles in and around a barn (see fig. 2). The barn was a 1:100 downscaled model from a barn situated in Dummersdorf (north Germany). Laser Doppler Anemometer measurements with a measurement uncertainty of 0.2 % were used.

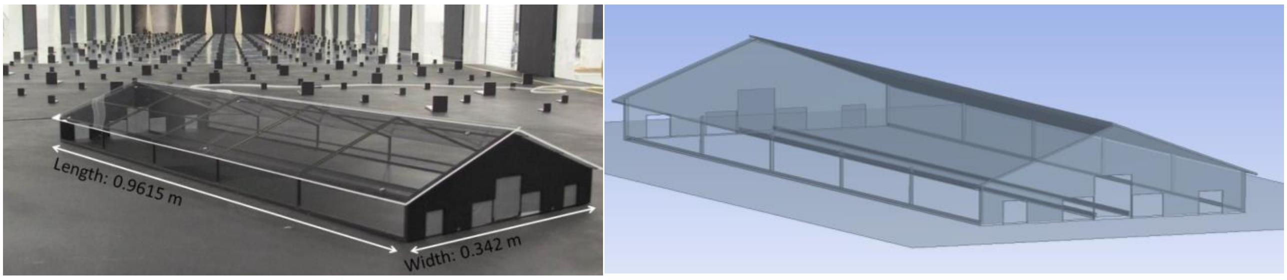

Figure 2. Left: 1:100 scale barn in wind tunnel, right: CAD model of scale barn

The experiment was used to validate the numerical model. The modeled barn geometry has been tested with the two mesh types: (1) a mesh with tetrahedral cells only and (2) a mesh with a combination of a structured (quadrilateral) and an unstructured (tetrahedral) mesh. Fig. 3 illustrates the comparisons of the velocity profiles in front of and behind the barn. The velocity profiles from the numerical simulation are in good agreement with the wind tunnel data.

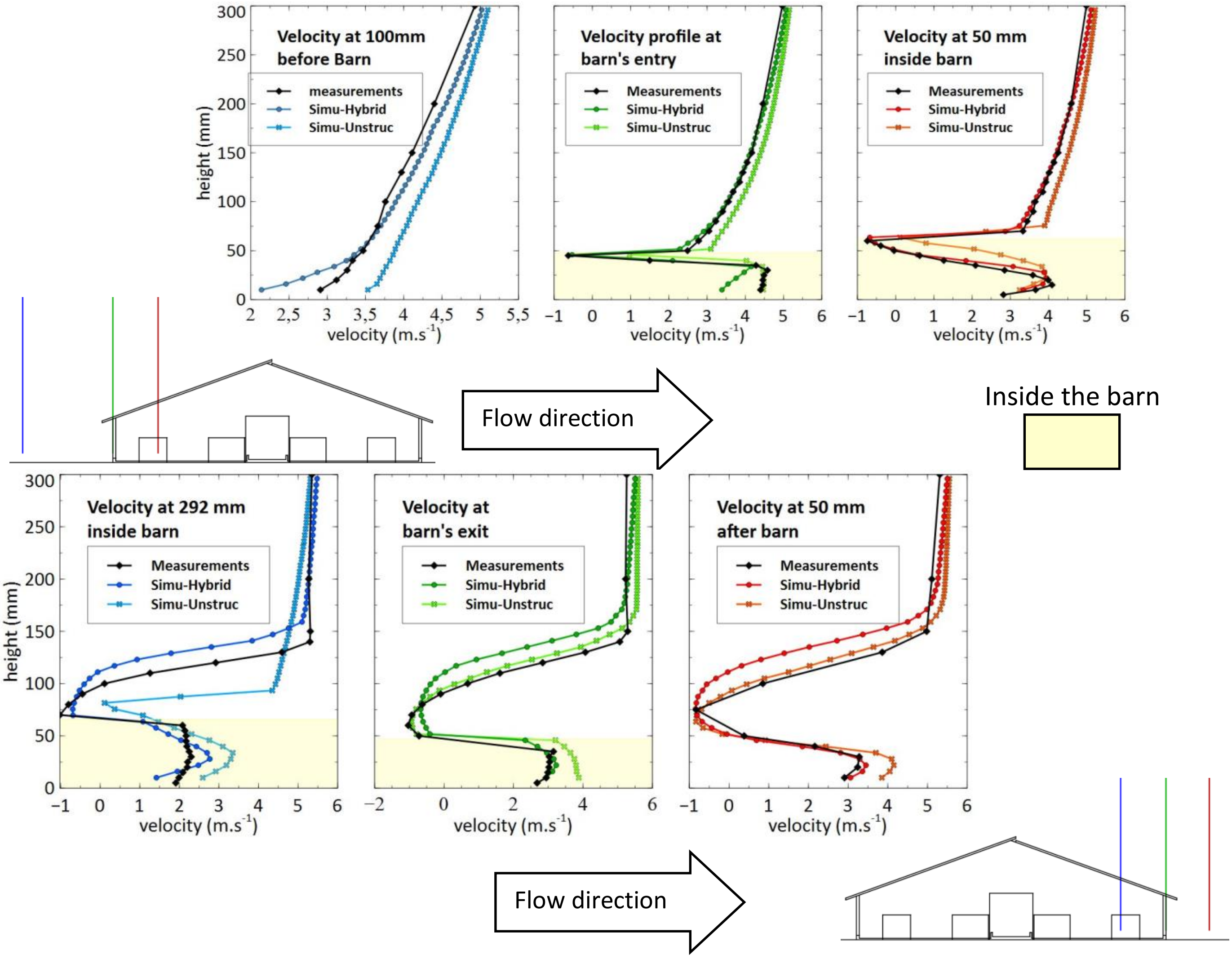

Figure 3. Model validation by comparing the vertical velocity profiles

3. RESULTS AND DISCUSSION

After the numerical model was validated, a series of simulations were carried out in order to understand the influence of barn design and the incident velocity angle degree. Since the validation was successful in scaled dimension, it was decided to keep the same scale (wind tunnel scale) for this investigation. The barn width/length ratio varied from 2 to 4 and the chosen incident wind directions were 0°, 45° and 90° degrees. Since the barn's geometry and AOZ placement are symmetric in the *x* and *y* directions, those directions are sufficient to represent incident flow from all directions. In addition, the velocity magnitude of the wind entering the barn was varied as well by 1, 3 and 5 m s^{-1}. A particular attention was paid at the AOZs inside the barn (nominated $X_a Z_b$, with a=1,2 and b=1..L/W). These zones are important, since their air exchange rate (denoted AER_{AOZ} in the following) gives the information of how much fresh air the animals are receiving and if this amount is sufficient. Fig. 4 shows the AER magnitude as color-coded maps for 0°, 45° and 90° incident velocity angle (from left to right) for an incident velocity of magnitude 5 m s^{-1}. One can notice that there is a distinct pattern for each incident velocity angle.

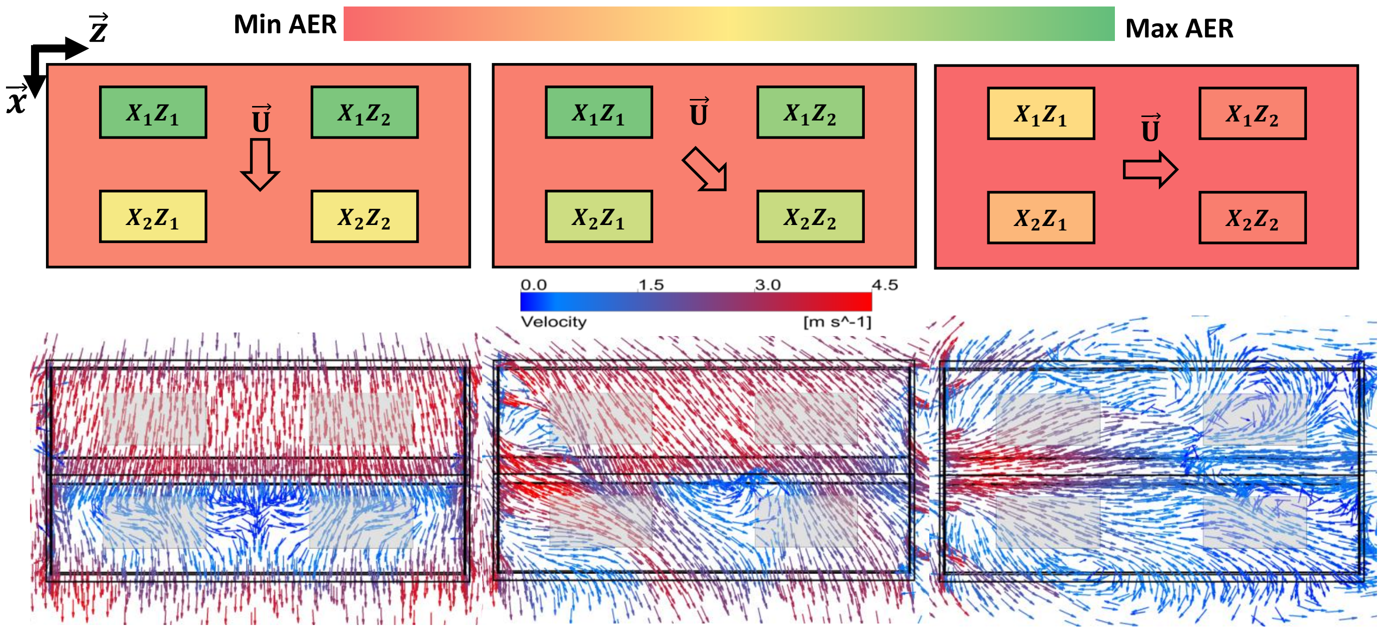

Figure 4. Up: AER of the whole barn *L/W*=2 and the AOZs for different incident velocity angles (from left to right: 0°, 45°, 90°), down: corresponding velocity vector field at the middle of AOZ height; velocity magnitude 5 m/s.

For the 0° angle case, the AER_{AOZ} of X_2Z_1 and X_2Z_2 are around half the AER_{AOZ} of X_1Z_1 and X_1Z_2. The AER_{AOZ} are more uniform for the 45° angle case. In the case of 90°, where the air enters the barn mainly through the gates of the side wall, the AER are the smallest of the three incident angles. The same patterns can be observed for the other velocity magnitude 1 m s^{-1} and 3 m s^{-1}.

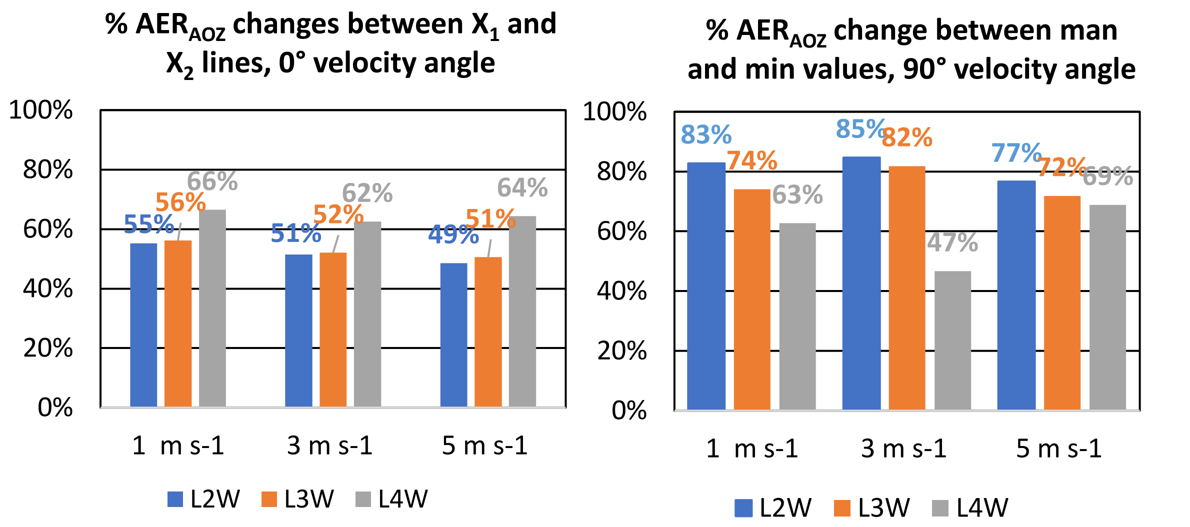

Figure 5. Left: Percentage of (AER_{X1}-AER_{X2})/AER_{X1}, 0° incident angle; Right: Percentage of AER_{AOZ} (max-min)/max, 90° incident angle; for all *L/W*.

Fig. 5 shows the quantitative impact of the velocity magnitude on the AER_{AOZ} for 0° (i.e. cross flow) case and the 90° (i.e. side flow) case. The left graphic compares in percentage the difference between the average AER_{AOZ} of the first line (X_2) and the second line (X_2) for all L/W ratios for the 0° case. With increasing velocity a slight decreasing trend is observed in the AER_{AOZ} (except for the case *L/W*=4 with 5 m s^{-1}). In addition, for all studied velocities, there is a more significant decrease of the AER_{AOZ} of the second line X_2 relative to the first line when *L/W*=4 (around 35 % the AER_{AOZ} of the first line X_1) compared to *L/W*=2 and 3 (around 50 % the AER_{AOZ} of the first line). The right graphic of Fig. 5 shows quantitatively the relative difference height of variation between the extreme values (max and min) of AER_{AOZ} for the 90° incident angle. The minimum AER_{AOZ} is typically more than 1/3 of the maximum AER_{AOZ}. For longer barns (bigger *L/W*), the difference between max and min AER_{AOZ} is becoming smaller while an opposite trend can be observed for 0° case.

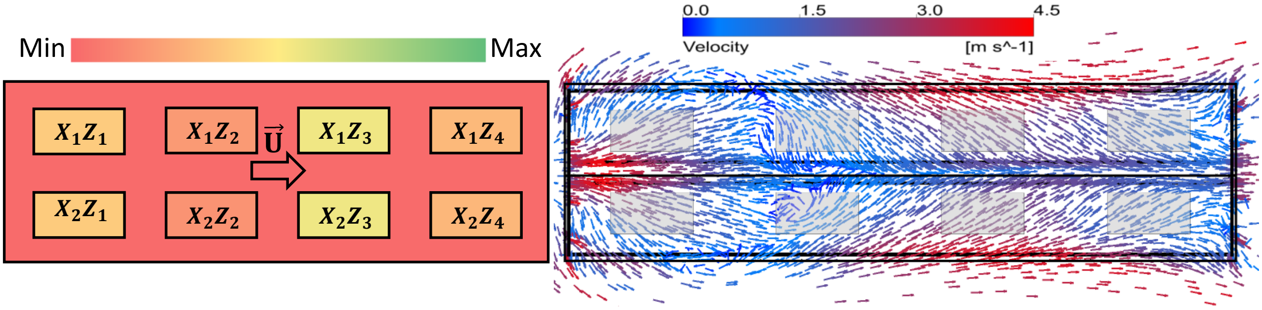

Figure 6. Left: Barn AER and AER_{AOZ}, L/W=4, 90° incident angle, 5 m s^{-1}; Right: corresponding velocity vector field.

Another interesting pattern can be seen for 90° incident angle in Figure 6. The AER of the AOZs are almost symmetric with respect to the z direction and are alternating between high and low values from one AOZ to the next one.

4. Conclusions

This study provides valuable qualitative and quantitative information about the air flow in a naturally ventilated barn. For incident wind in prevailing wind direction (0°) and perpendicular to this direction (90°) the lowest value among the air exchange rates of the individual animal occupied zones, min(AER_{AOZ}), was at least one third of the maximum value, max(AER_{AOZ}). For a 45° incident wind angle the differences between the individual AER_{AOZ} were the smallest. For the 90° incident wind angle the lowest local air exchange rates were observed. Each incident wind angle produces a particular pattern inside the barn, with a tendency to higher values at the windward side of the building. For 90° an oscillation pattern was observed.

Future work will take into account the convection and gas flow in a real sized barn in the pursuance of a better comprehension of AER dependency.

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MACHINE LEARNING ALGORITHMS COMPARISON FOR IMAGE CLASSIFICATION ON ANTHRACNOSE INFECTED WALNUT TREE CANOPIES

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ABSTRACT

Fungal diseases such as anthracnose, can be catastrophic to crops worldwide because it can destructively damage the canopies of trees and can also spread easily to nearby trees. Copper spaying, adequate pruning and proper sanitation, renders the treatment of such diseases as easy, however, the main concern in such cases is the spreading prevention by early detection systems. This can be dealt with automated procedures offered in precision agriculture such as automatic image collection and real-time classification by smart systems. Purpose of this study is to compare the most famous ML algorithms for classification, in order to investigate the applicability and effectiveness of an image-based classifier on anthracnose infected canopies. Various machine learning algorithms were employed, tested, evaluated and compared based on their abilities and limitations. The comparison is conducted based on several performance metrics and finally, the applicability of the best performing architecture is discussed for real-life applications.

Keywords*:* machine learning, image classification, anthracnose, walnut trees

1. INTRODUCTION

In agriculture, fungal infections can be catastrophic for entire crops, leading to diminished, and even destroyed yields. This problem affects directly the income of the farmers, and even though the disease can be treated easily, the aim is to prevent its spreading before it infects large areas. Autonomous systems that can identify the infection without any human input, can solve this problem by monitoring the status of each tree in the field, by collecting images of it. This approach can be built on machine learning algorithms (ML) which is used for this kind of applications (Bharate and Shirdhonkar, 2018; Liakos *et al.*, 2018).

Machine learning is a wide area of self-training algorithms that can learn to do tasks such as image classification. Several types of infections have been investigated for many types of plant leaves, leading to diverse approaches on image-based plant disease classification. Artificial neural networks (ANN), radial basis function networks (RBF) and learning vector quantization (LQV) were used by (Muthukannan *et al.*, 2015) achieving 56.7%-90.7% accuracy, support vector machines (SVM) and ANNs were used by (Ramya and Lydia, 2016) achieving 88%-92% accuracy, advanced deep neural

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networks (DNN) were used by (Picon *et al.*, 2018) achieving 96% accuracy, and convolutional neural networks (CNN) by (Mg *et al.*, 2017) that managed 96.3% accuracy.

More advanced variants of CNN have been able to achieve higher accuracies in more complicated, multi-class classification problems. Notably, (Sladojevic *et al.*, 2016) reached up to 98% for 13 types of plant diseases, (Ferentinos, 2018) achieved 99.53% for 25 plant types with 58 diseases, (Mohanty, Hughes and Salathé, 2016) achieved 99.35% for 14 plants and 26 diseases.

The classification of multiple types of infections was studied on tomato leaves by (Fuentes *et al.*, 2017), wheat by (Wang *et al.*, 2012), banana trees by (Amara, Bouaziz and Algergawy, 2017), on brinjal (aubergine) by (Anand, Veni and Aravinth, 2016) and on apple trees by (Wang, Sun and Wang, 2017) and (Liu *et al.*, 2018).

We focus on the proper classification of images containing leaves from walnut trees, that are both infected by anthracnose and healthy. We investigate the performance of the most famous classification ML algorithms on this problem, in order to understand the pros and cons of each approach.

The structure of this paper is as follows: in paragraph 2 we present the methodology that was followed for the acquisition and the preparation of the data, the ML algorithms that were tested and the performance metric that were used for the evaluation, in paragraph 3 we present the results of the investigatory study, and in paragraph 4 a short discussion as well as the conclusions of our study.

2. Methodology

Anthracnose appears as brown or brown-yellowish marks on the leaves of the walnut tree. The marks usually appear as spots on the surface, or they cover the perimeter of the leaf. For the human eye, the symptoms of anthracnose (or of similar illnesses) are easy to detect. The aim is to identify the machine learning methodology that can perform as well as this human perception. The methodology that has been followed in this study, is presented in the next paragraphs.

2.1 Data acquisition

Image-based classification requires a large number of data, with distinct features in order to be able to train successfully a model to predict a class. A total number of 2.000 leaf images was collected from a walnut crop field located in Rizomylos Volos, Greece. The dataset was balanced with half of the images to contain leaves which are infected by anthracnose, and half that are healthy. In Figure 1 (a) we can see an indicative image from a healthy leaf, and in Figure 1 (b) a leaf infected by anthracnose.

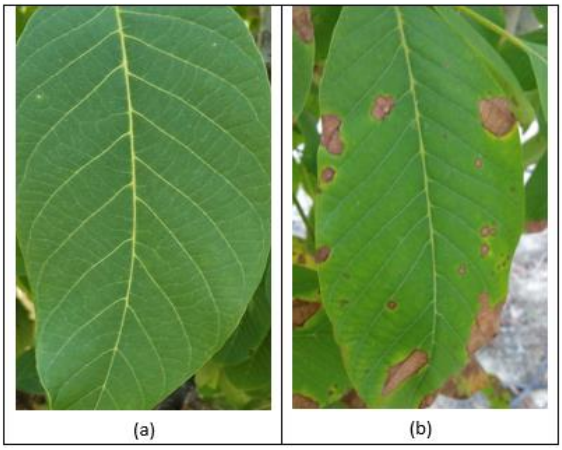

Figure 1. Walnut tree leaves without (a) and with anthracnose (b).

2.2 Data preparation

Each image was originally resized into a 128x128 pixel resolution. This resolution is large enough to keep the characteristics of the leaf, and also small enough to be able train the model within a desired time. Since colour information is important for the identification of anthracnose, all images are collected as RGB and as such as are used in the algorithms. Each image is then reshaped, by transforming from a 128x128x3 shape, into a 1x49,152 vector. This was conducted for each image, leading to a 2,000x49,152 matrix of pixel-wise features. One last column is being added to the matrix,

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containing the label of the image (i.e. 'Anthracnose' or 'Healthy') therefore the matrix becomes 2,000x49,153. The label column which now is categorical, is being encoded into binary representation, '0' for anthracnose and '1' for healthy. Finally, the rows of the dataset are being shuffled twice, with two different random-generated methods in order to avoid a biased sampling, that would lead to improperly trained models.

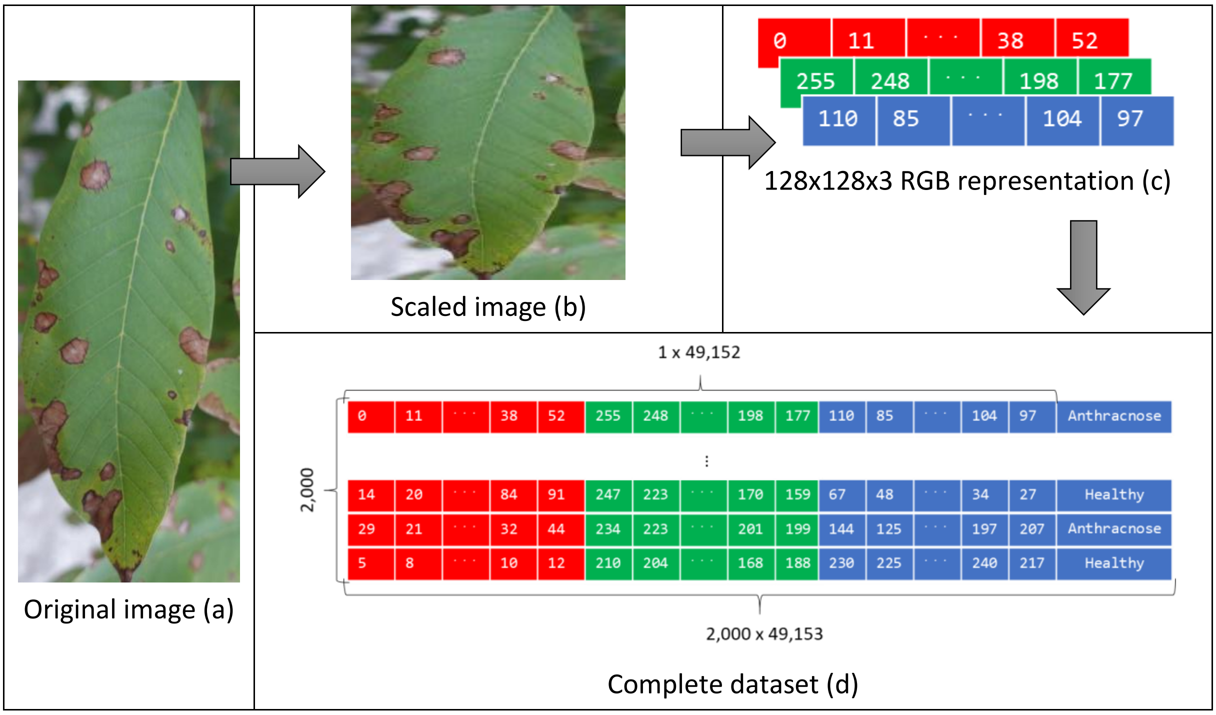

Figure 2. Data preparation from original image (a) to scaled image (b), to RGB tables (c), and finally to pixel-wise dataset (d).

2.3 Data split

Before any implementation to the models, the dataset is being split into three sections. Initially, the dataset is divided into training and testing with an 80/20 rate respectively. The testing portion is completely hidden from the model training process (hold-out), in order to obtain predictions that are unknown to the trained classifier. The second split regards the training dataset, of which the 20% is used for validation. The purpose of that is to make sure that the algorithms do not overfit during training, in order to keep good generalization for the model. Once the model is trained, the testing dataset will be used to make predictions, and based on that, the accuracy of the model will be obtained.

2.4 ML Methods

For our study, we have chosen 11 of the most famous ML algorithms in order to see how well each of these different methodologies can achieve reliant performances. These ML algorithms and the particular implementations are described shortly.

The Bayesian algorithms, Gaussian Naive Bayes (GNB) (Russell and Norvig, 2002) and Linear Discriminant Analysis (LDA) (Büyüköztürk and Çokluk-Bökeoğlu, 2008), suited for high-dimensionality problems, were implemented with no prior probabilities for the classes, and with the singular value decomposition (SVD) solver for the LDA. The k-Nearest Neighbours (kNN) (Altman, 1992), an instant-based learning algorithm where the function is only approximated locally, and all computation is deferred until classification, was implemented with 5 neighbours (*k*). The Decision Tree (DT) (Breiman,

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1984), which builds a classification model in a tree structure, learns simple if-then decision rules, which offer interpretability and require minimal data preparation. Three ensemble classifiers, Random Forest (RF) (Breiman, 2001), Adaptive- (Adaboost, Ada-b) (Freund and Schapire, 1996) and Gradient-Boosting (Grad-B) (Mason *et al.*, 1999), methods that create strong classifiers by combining weak learners such as DT and bootstrap aggregating to obtain better predictive performance than could be achieved from the constituent algorithms on their own, were implemented with DT as weak learners, and 100 estimators each. Support Vector Machine (SVM) (Vapnik, 1999), a supervised learning algorithm with main aim to plot data is higher dimensionality spaces and find a hyperplane that differentiates classes by maximizing the distance between the hyperplane and the closest data point from each group, was implemented both with a radial basis function kernel, and with a *nu* parameter, set to 0.5, which is used to control the number of vectors. Finally, two Artificial Neural Networks (ANN) (McCulloch and Pitts, 1943), computing systems inspired by the biological neural networks were implemented. A multi-layer perceptron (MLP) with one hidden layer of 100 nodes, and a deep neural network (DNN) with a 5-layer architecture, an 8, 16, 16, 16, 16 node configuration and a 50% dropout rate per hidden layer. Both were implemented with 'ReLU' activation in all hidden layers, and sigmoid function for the output layer, since we have binary classification. 'Adam' optimizer and early stopping with 10 epochs patience were used for the training.

2.5 Performance metrics

The performance metrics used in this study are described in this paragraph. After a classifier is trained, it predicts the class of a new entry from the testing set. Depending on the prediction and the actual class it belongs, this prediction can be true positive (TP) or true negative (TN) if it is classified correctly, or false positive (FP) or false negative (FN) if it is misclassified.

Accuracy is the most intuitive metric, considering symmetric datasets, and is defined as the ratio of correctly predicted observation to the total observations (TP+TN/TP+FP+FN+TN). Precision is the ratio of correctly predicted positive observations to the total predicted positive observations and is defined as (TP/TP+FP). Recall is the ratio of correctly predicted positive observations to the all observations in actual class (TP/TP+FN). F1 Score, which is preferred when the class distribution is unbalanced, is the weighted average of Precision and Recall (2*(Recall * Precision) / (Recall + Precision)).

Finally, logarithmic loss measures the performance of the classification model where the prediction input is a probability value between 0 and 1. Log loss increases as the predicted probability diverges from the actual label with ideal goal to minimize this value to 0. For the calculation, a probability is assigned to each class rather instead of yielding the most likely class. Mathematically, log loss for binary classification is defined as:

$$-(y\log(p) + (1-y)\log(1-p)) \quad (1)$$

where y is a binary indicator (0 or 1) of whether a class label is the correct classification for a given observation, and p is the model's predicted probability that the given observation belongs to a certain class.

3. Results

The results of the ML algorithms are presented in this section. All algorithms were trained on a Nvidia Titan 1080 Ti, and were programmed on Python's Sci-Kit Learn, Keras (with Tensorflow), Pandas, and Numpy libraries. In Table 1, the results of all the tested ML algorithms are presented

Table 1. Performance metrics for the ML algorithms' comparison.

Algorithms	Accuracy	Precision	Recall	F1	Log Loss	Fitting time (sec)
GNB	81.25%	0.81	0.81	0.81	6.479	2.08
LDA	88.50%	0.89	0.89	0.88	0.532	10.2

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kNN	71.25%	0.8	0.71	0.69	4.503	3.02
DT	81.75%	0.82	0.82	0.82	6.303	36.7
RF	88.00%	0.88	0.88	0.88	0.369	1.44
Ada-B	87.25%	0.87	0.87	0.87	0.631	165
Grad-B	89.25%	0.89	0.89	0.89	0.247	328
Nu-SVM	89.25%	0.89	0.89	0.89	0.263	462
SVM	85.00%	0.85	0.85	0.85	0.338	472
MLP	87.75%	0.88	0.88	0.88	3.256	84.3
DNN	**90.25%**	**0.9**	**0.9**	**0.9**	**0.295**	**74**

Deep neural network, nu-SVM and gradient boosting achieved the best performance. These three algorithms were able to achieve a low logarithmic loss, however the training time of the DNN was significantly less compared to the others. Deep neural network seems to be the best performing algorithm for this application.

4. Discussion & Conclusions

A comparative analysis was conducted on the applicability and the performance of machine learning algorithms for image-based classification of anthracnose in walnut tree leaves. An adequate number of 2.000 images was obtained, with equal portions of healthy and anthracnose-infected leaves. A total of 11 ML algorithms were tested and evaluated based on their performance and the accuracy they achieved over the collected dataset. The algorithms' accuracies ranged from a 71.25% to 90.25%, with most of them reaching over 85%. The algorithm that achieved the best performance, was the deep neural network implementation, which also achieved a low logarithmic loss (0.295) and a average training time (74 sec) compared to the other algorithms. Considering the performance of the deep neural network architecture, image-based anthracnose detection of walnut tree leaves, is a viable option for application in a real-life field.

This exploratory analysis points the way towards a more in-depth study on the algorithms that are based on deep neural structures, such as convolutional neural networks (CNN) and recurrent neural networks (RNN). Future plans include investigation of more complex derivatives, as well as meta-architectures of CNN that can conduct object detection, as well as instance aware image segmentation. Additionally, pre-processing methods such as fast Fourier transformation and wavelet decomposition, should be considered for investigation.

As far as the author's knowledge, other studies have reached similar performances in the particular problem of walnut trees/anthracnose (Gamal *et al.*, 2017). Aim for this study and its continuation is to build a ground-up, high-accuracy (>99%) classifier, based on real-conditions dataset of walnut trees' canopies. This way, robust, autonomous systems will be able to detect the disease on leaves, with high confidence, without human supervision.

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Combined UGV and UAV perception of field areas as operational environments

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Abstract

Detailed information of the structure of the surface in the extremely demanding and continuously changing environment of agricultural fields is essential for the automated navigation of unmanned ground vehicles (UGV). Unmanned aerial vehicles (UAVs) can rapidly provide essential information for this purpose. Hence, in this work the conceptualization of an inter-communication system UAV and UGV communication is proposed. The aim of the developed system is the cooperative UAV - UGV path mapping procedure for large-scale areas in tandem with the depletion of the operational costs related to the operational environment awareness. In order to accomplish the above-mentioned concept, state of the art technologies and algorithms were incorporated. According to the concept, the UAV executes an automated flight, detects the cultivated trees, extracts their coordinates and sends them to the UGV. As a final step, the UGV creates a pseudo 2D map with all the identified trees and the path to follow during the operations in the field. The developed system was tested in real field conditions in a commercial walnut orchard providing satisfactory operation.

Keywords: perception mapping, autonomous navigation, UAV, UGV

1. Introduction

With the introduction of Agriculture 4.0 concept, innovative technologies from numerous scientific areas have been implemented in order to facilitate the traditional agricultural methods (Weltzien, 2016; Ozdogan, Gacar and Aktas, 2017; Liakos et al., 2018; Angelopoulou et al., 2019). In tandem with operational efficiency, robotic systems (both ground and aerial) aggregate towards a promising alternative to the traditional intra-logistic operations within the field. For the purpose of the above, an essential step has to take place. The mapping procedures constitute a cornerstone towards fully automated operations that take place in outdoor operational environments. To cope with the abovementioned structure, various in-door mapping algorithms used by unmanned ground vehicles had been amended. The geomorphological divergence between the indoor and the outdoor environment along with the imponderable factors (weather, constantly changing environmental conditions, large-scale areas) that occur in the agricultural environments led to the deployment of the unmanned aerial vehicles for agricultural use.

Mapping of the physical environment of agricultural fields constitutes an essential operation towards the automated navigation of robotic technologies within agricultural operational environments (Bochtis et al., 2009, 2015; Kurashiki et al., 2010; Hameed et al., 2012; Hansen et al., 2013; Tokekar et

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al., 2016). Dynamic technologies are implemented to cope with the large-scale, in terms of area, and extremely demanding agricultural environment which is constantly changing. To that end, state-of-the-art technologies from various scientific fields have already been assimilated under the auspices of Agriculture 4.0. Additionally, the constantly increasing available computational power facilitates the development of Deep Learning (DL) methodologies in various agricultural applications to support farm management practices.

Numerous studies were conducted in the area of tree identification. Yang *et al.*, (2009) proposed a system that uses Adaboost algorithm to detect trees from aerial images. The fine-tuning of the Adaboost algorithm was took place in the work of (Greenberg, Dobrowski and Ustin, 2005). As a pre-processing method, all the imported images were transformed to the CIE L*a*b* color space to eliminate the shadow effect. Finally, they proposed a localization method in order to estimate the actual size of the identified tree.

The work of Amorós López et al. (2011) proposed a system for citrus grove identification and localization. The proposed method included the incorporation of RGB and NIR images as input for the trained model. Moreover, three machine learning methods were tested in order to optimize the produced results; a MultiLayer Perceptron neural network (MLP) (Duda, Hart and Stork, 2001), a Classification and Regression Tree (CART) classifier (Breiman et al., 2017) and a Support Vector Machine algorithm with the latter delivering the most accurate results.

In this study the conceptualization of an inter-communication system for UAV and UGV communication is proposed. The developed system provides the cooperative UAV - UGV path mapping procedure for operational environment awareness by the UGV. Preliminary test of the system performance took place in a commercial walnut orchard.

2. METHODOLOGY

The field work for data collection and system validation took place in 2018 and 2019 in three commercial walnut orchards located in Magnesia, Central Greece. The orchards were flat and there were no significant geomorphological variations. The first step of this work included the data aggregation for the training of the model to be developed. The eBee+ drone (fixed wing) was used to aggregate all the necessary data. The eBee+ (SenseFly, Switzerland) was equipped with an RTK GPS and a high resolution RGB camera (S.O.D.A., SenseFly, Switzerland). The UGV used in this work was the Husky robot (Clearpath Robotics, CA).

A machine learning algorithm was trained in order to identify the cultivated trees. The produced model was integrated in a Raspberry Pi along with an RGB camera. The overall scope of this sub-system was to take as input the real-time feed from the RGB camera and to export the position of the trees. Finally, a two-way communication between the UAV and the UGV was developed. Furthermore, an algorithm was developed and integrated into the UGV’s computer for processing the aggregated data and creating the pseudo 2D map. The whole procedure of the proposed system is described in figure 1.

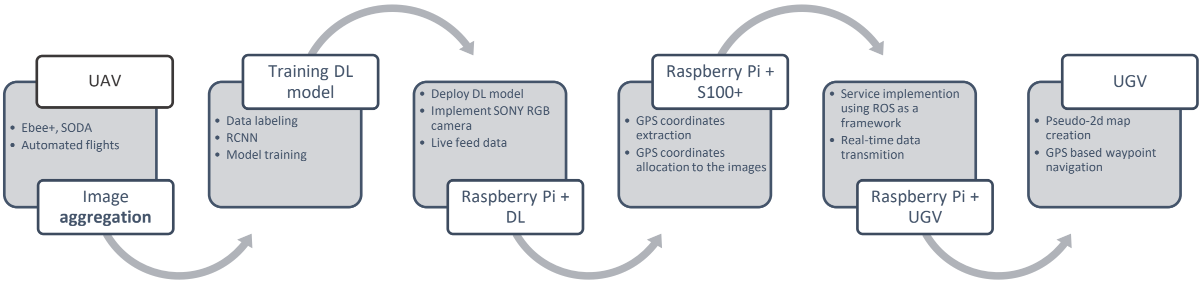

Figure 1. Flowchart of the proposed system

2.1 Image Aggregation

In order to aggregate all the necessary data for the model training, numerous automated flights took place at the walnut orchards (***Figure 2***). The collection of data required for the development of the model carried out at three different stages of the walnut's development, during May after leaf growth, November when the leaves were brown and the trees were defoliating (post-harvest), and December during dormancy when the trees were fully defoliated.

Figure 2. UAV flight plans for the three commercial walnut orchards used in the study

2.2 Software Implementation

2.2.1 Deep Learning algorithm

During the data acquisition process 1869 images were acquired in total from all three fields and development stages (August, November, December). All the datasets were aggregated. The 75% of the images were manually classified and used for training and the 25% for testing purposes.

The proposed system utilizes fast RCNN algorithm for identification and localization with ReLU as an activation function and 100 epochs. Moreover, as a pre-processing method, all the images were converted to the HSV color space to disentangle the image entities.

2.2.2 Raspberry Pi

The trained model was deployed in a raspberry 3 which was connected to the RGB camera. Live feed from the camera was transferred to the raspberry Pi in order to enable the trained model to identify the walnut trees. To further explore, the position of the UAV was transferred to the raspberry from the Pixhawk autopilot.

An algorithm was developed to assign coordinates to each pixel of the image and to correlate the points of interest (areas within the image with the identified trees) with the generated coordinates. Finally, with the use of the Robot Operating System (ROS) and a compatible package (mavROS) to incorporate the telemetry protocol which is used by the UAV to communicate with the ground station. the extracted coordinates from the identified trees were transferred to the UGV.

2.3 HARDWARE IMPLEMENTATION

To validate the proposed system, modifications in a UAV was took place in order to be equipped with the Raspberry Pi and be able send the necessary data to the UGV. All the autonomous flights were executed as a survey with the QGroundControl. The DJI S1000+ octacopter (SZ DJI Technology Co., Ltd., Shenzhen, China) equipped with Pixhawk 2.1 autopilot (Proficnc®), Here+ GPS (Proficnc®) and Sony Cyber-shot RX100 III digital camera (SONY, Minato, Tokyo) was utilized to execute automated flights over the orchard and acquire high resolution (0.9 cm/px) RGB images

In order for the data to be obtained properly, a ROS service was developed within the UGV's ROSMATER. The service required a simple Boolean handshake in order to initialize the data transition. This is a real time approach according to which, as the trees are identified by the system they are instantly arranged in space in order to create the psedo-2DMap with the tree positions.

The UGV used in the study was the Husky robot equipped with RTK GPS (with 10Hz position refresh rate), IMU and a 3D Velodyne laser scanner for real-time obstacle avoidance. The system was tested in real field conditions to evaluate the communication between the UAV and UGV and for the proof of concept of the study.

3. RESULTS AND DISCUSSION

To validate the proposed system, images from all three walnut orchards were aggregated to examine the accuracy of the system in orchards with different properties. The actual location of the trees was manually recorded and used for ground truthing. The results from the developed image analysis procedure were compared with the manually recorded tree locations.

Figure 3. Trees identified by the developed system for the image acquired during (a) May, (b) November and (c) December

In the dataset of the images acquired in May, when the canopy was developed, the algorithm responded very well identifying the trees with high accuracy (100%). The tree recognition accuracy was adequate, but considerably lower compared to the May results, for the November image dataset. This was attributed to the fact that the trees were defoliating and the color of the leaves was turning brown, becoming difficult to distinguish. Even more challenging for the algorithm was the image dataset acquired in December, thus the results showed poor recognition accuracy (32.7%) (Table 1).

Table 1. Accuracy of trees recognition using the developed methodology for images taken in May, November and December

Variables	Precision (%)
May	100
November	85,7
December	32.7

The information of the trees position was sent to the UGV. To verify the produced results a pillion mission was conducted. In this mission the UGV was successfully navigated in the walnuts' orchard avoiding all the static obstacles.

5. Conclusions

The proposed approach consists a promising solution for real-time large-scale perceptional mapping of orchards physical environment. The main advantage of this work is the independence of the system from third-party and closed source software. Hence, the open source nature of the system provides easy deployment to various case studies. Another essential advantage of the proposed system is the ROS interaction of the autonomous vehicles (UAVs and UGVs).

The produced results confirmed the benefits of machine learning algorithm for image segmentation applications. The developed system was very accurate in recognizing the trees from images acquired when the trees canopy was developed. The accuracy dropped as the canopy was becoming difficult to distinguish at the stages after defoliation.

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SPATIAL OPTIMIZATION FOR ORCHARDS IN COMPLEX FIELD AREAS

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ABSTRACT

The establishment is a cornerstone work for orchards and paradoxically is mainly based on empirical and traditional knowledge. This results to low or no improvement at all over the years and even less likelihood to adopt and harness the power of the new technological breakthroughs. The proposed system takes advantage of the abundant computational power to recognize and adapt planting patterns to complex field shapes. Enhancements include among others the integration of new spatial work requirements stemming from the emergent agri-robotics machinery field that can be input data for the design process. Also, the ability to dry run different planting patterns to fully optimize surface coverage. Furthermore, the work includes modules that quantify and integrate micro-climatic factors, optimizing in a non-uniform method the planting pattern. This feature is ground-breaking especially in cultivations that require pollinators, where standard practice was to set a percentile of pollinators, severely affecting productivity. In the work presented the algorithm is shown to be able to reduce the number of pollinators without decreasing their effectiveness, using grid deformation techniques, clustering algorithms with modified criteria imposed by the needs of the agronomic system. The results show significantly increased productivity potential attributed both to the reduced number of pollinators required and the increased spatial efficacy. Additionally, the fully digitized operation offers enhanced postprocessing capabilities to the farm manager as well as a digitized ground truthing tool.

Keywords*:* orchard, establishment, spatial, optimization, algorithm**.**

1. INTRODUCTION

Orchard cultivation has increased in the last 25 years both in area coverage and in crop production. This is verified by statistical data provided by FAO. For three major categories of orchards, fruits, olives and hard-shell nuts data show that the area used for each has increased by 32%, 42% and 32% respectively, depicting a clear shift towards orchard cultivations. Orchards have been studied in depth due to their long economic lifespans and the limited ability to be take corrective actions after their establishment. This particular feature has fuelled development of early algorithmic tools to pre-plan planting patterns, randomising spatial arrangement and ensuring bio-diversity (Giertych, 1975; Bochtis et al., 2007). Initial work was further extended and evolved to permuted algorithms (Bell and Fletcher, 1978) laying ground for development of algorithmic tools for agriculture. Increase of computational power and advances in computational frameworks led to modern heuristic based approaches

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(Chaloupková et al., 2016) and to simulation tools that can predict efficiency of spatial arrangements (Bochtis et al., 2009, 2010, Hameed et al., 2010, 2012, 2013; Sáez et al., 2018).

Simultaneously robotic applications are being developed for all cultivations and with some focusing particularly on orchards (Fountas, Søren Pedersen and Blackmore, 2005; Won Suk Lee, Chinchuluun and Ehsani, 2009; Bochtis et al., 2015). To build and sustain a fully automated system in agriculture, the need for planning with the aid of algorithmic tools is increasing. In this light, the work presented will address the problem of establishing an orchard taking fully advantage of the available technologies and output an optimised planting pattern that contains all the necessary information for autonomous or conventional agricultural machinery to execute the task.

2. Methodology

To develop an algorithmic tool that covers all the targeted operations related to the orchard establishment we identified four major groups of functionalities as seen in Figure 1. The first group of parameters refers to plot geometry that needs to be defined by the user as an entity and provide extended information. The second group refers to the planting pattern that will be used, followed by the climatic constituent (Third module). Lastly, the fourth module pulls data from all the other modules to produce the optimal positions for pollinator placement. The modules will be explained in more depth in the sections that follow, as well as their interdependencies that will become evident as the algorithm is described in detail.

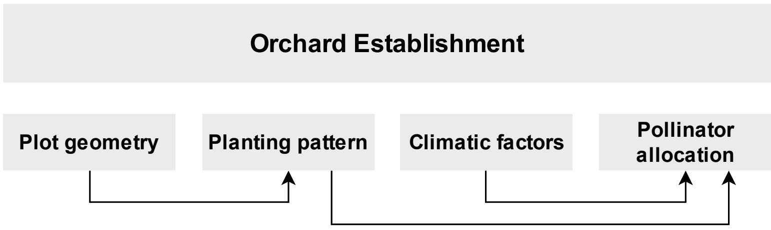

Figure 1. Four groups of functionalities

2.1 Plot geometry

The shape of the plot has a significant impact on planting operations. Even though orchards differ from arable farming considerably, the requirement for machinery to be able to access every point in the orchard is still fundamental, even more in a precision agriculture (PA) framework where machinery equipped with the respective implements need to be employed. Consequently, the design of the orchard needs to facilitate these needs and furthermore foresee the requirements of future machinery, since as mentioned above orchards are long-term investments. In a 20 to 25 years timespan disruptive technological advances are to be expected and therefore need to be factored in the planning stage. The initial input to the system is the set of coordinates that define the plot in question. The To ensure maximum compliance with the user's position towards innovation and future planning, the software doesn't force the optimum solution on the user, instead it asks for user input to define the primary parameters of the field, namely entry-exit point and major direction. These two elements define the starting point of the planting and the direction of rows. Compliant to empirical practices, the direction of rows is defined uniquely by user input that indicates the approximate direction, which is used in a calculation based on plot coordinates to fully define the exact direction and align the rows to the user selected plot side. Completing this module are the data related to headlands and side offsets, which are freely defined by the user.

2.2 Planting pattern

Having delineated the planting areas and their headings, the user needs to input data regarding the planting pattern. By entering the inter-row and the intra-row distance the pattern is fully defined, and the algorithm can populate the matrices related to the particular plot. The tree placement is confined by the plot and the respective offset distances entered in the initial module. Furthermore, the heading of the planting also influences the planting pattern. To reduce computational cost and round-off errors, the algorithm works selectively in the absolute and a relative coordinate system whichever provides the maximum benefit.

2.3 Climatic factors

Integrating climatic factors into the algorithm introduces the weighting system that the pollinator allocation module is going to use to enhance allocation by taking into account enhanced meta-spatial information. To quantify the effect of climatic factors, a weight function is introduced that takes into account the type of parameter that is being introduced and the relative position of trees in the orchard. The resulting matrix is a temporal dimension related to the climatic factor, normalized for simplified use as a weight function. This is the final computational step that requires user input for data, since the fourth module uses the data computed on the first three and modified clustering algorithms to achieve output results, without the input of the user.

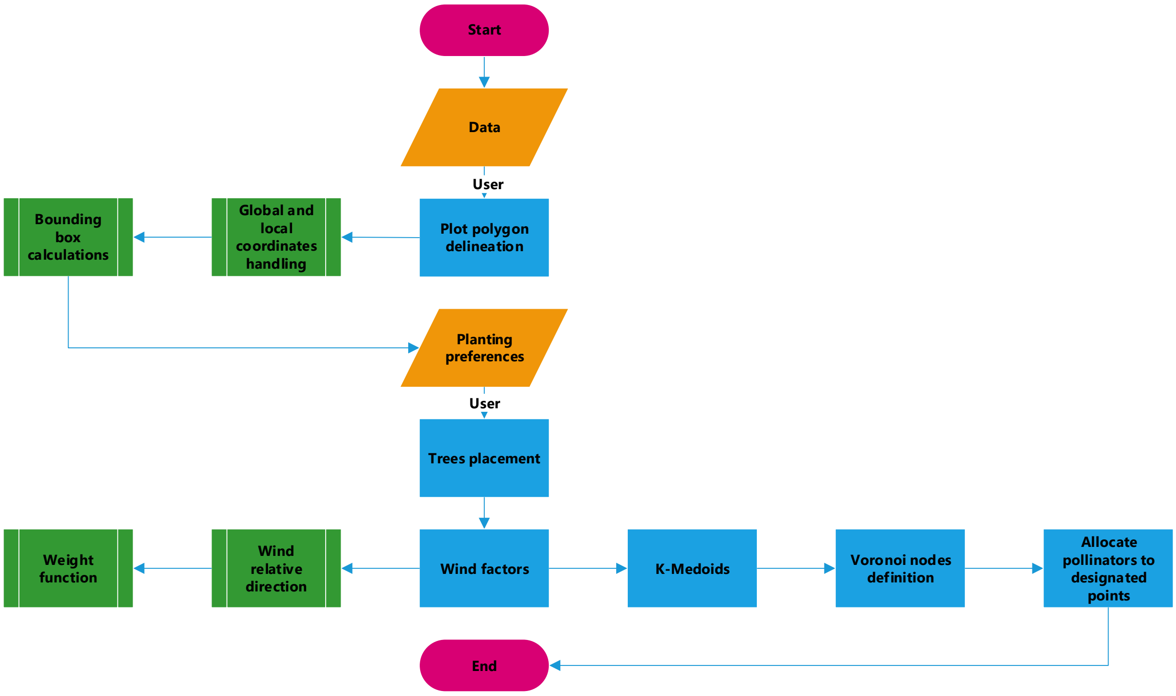

Figure 2. Flow chart of the proposed method

2.4 Pollinator allocation

In empirical practices pollinators are planted at regular intervals since the requirements for their function is defined solely by their percentile in the orchard. Uniform allocation ensures a degree of homogeneity for the field and in some cases, this leads to the dedicated use entire rows for pollinators. In this work, pollinators are placed either by spatial clustering using Voronoi polygons or according to their functional potential that is strongly influenced by wind direction and speed. This dimension is included with the use of weights. The method we implemented for allocating pollinators is a reverse approach to the problem, wherein clusters of trees are formed according to their position and their weights. The number of clusters N is calculated by the percentile of pollinators needed for the cultivation. The clustering algorithm used is a modified K-Medoid, producing clusters of defined minimum size with the centroid of the cluster designating the pollinator position. The flow chart for the proposed method is shown in Figure 2.

3. RESULTS

The algorithm was run to plot the tree positions using all three methodologies; empirical with a 25% of pollinators, Voronoi polygons clustering at 8% pollinators and modified weighted K-Medoids clustering at 8% pollinators. The inter- and intra-row distances were set to 8 meters and the diamond layout was chosen. The plot used is 200m by 400m and trapezoidal, resulting in 897 tree positions available.

To compare theoretical effectiveness a performance measure had to be defined. This was the mean distance of trees to the pollinator within the cluster. Despite the significantly lower percentile of pollinators, both Voronoi and modified weighted K-Medoids algorithms performed well and confirmed the improvement potential of the system. Results are shown in Figure 3 toFigure 6. Furthermore, mean distances and standard deviations are presented on Table 1. Allocation methods resultsTable 1.

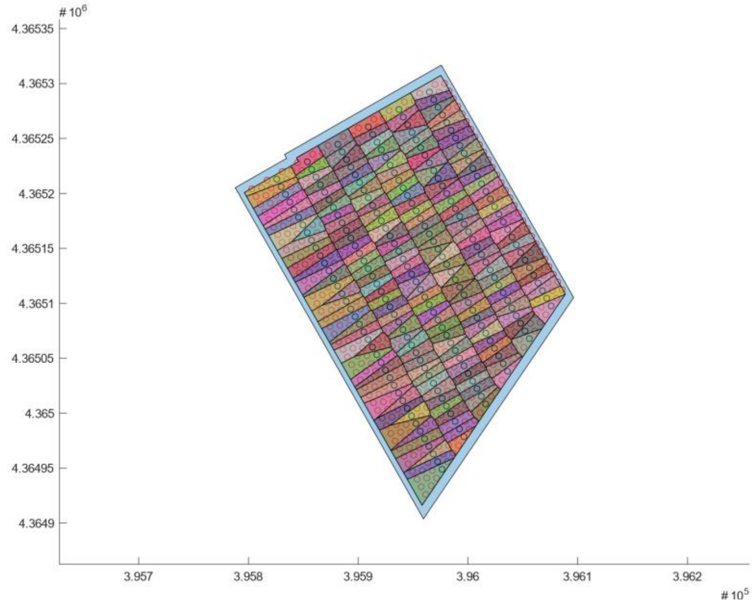

Figure 3. Empirical allocation of pollinators

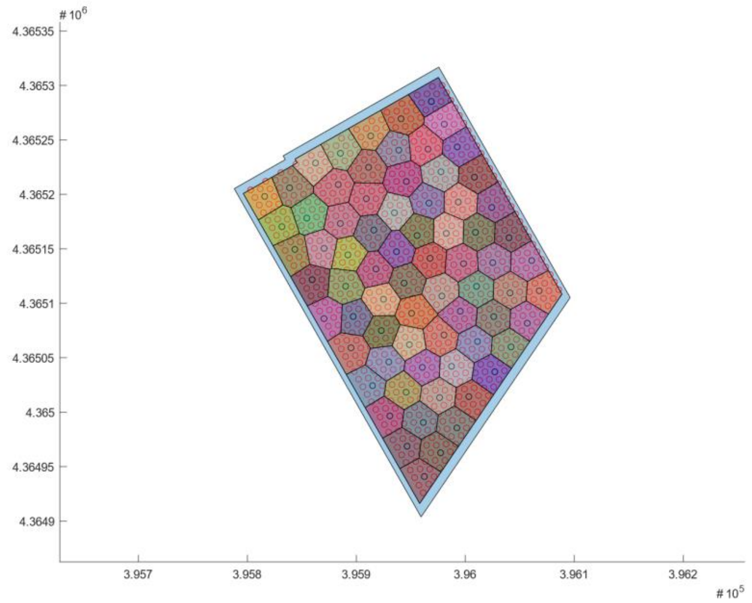

Figure 4. Voronoi allocation of pollinators

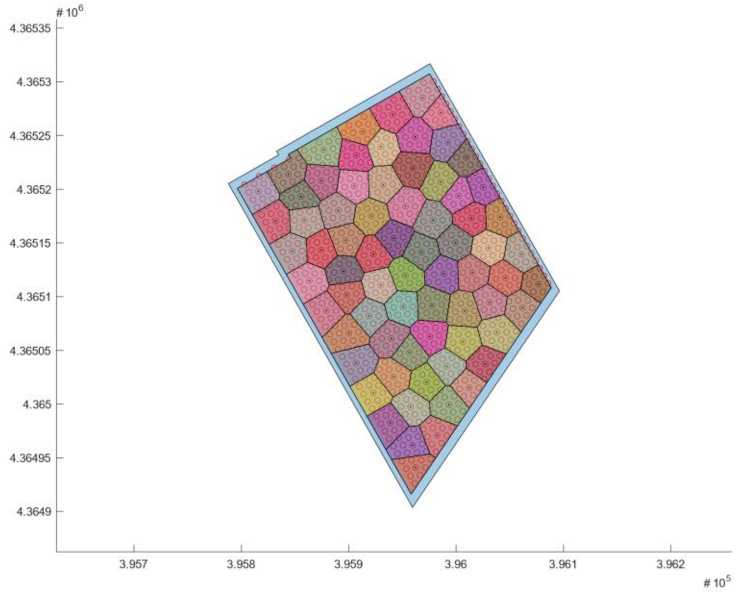

Figure 5. K-Medoids allocation of pollinators

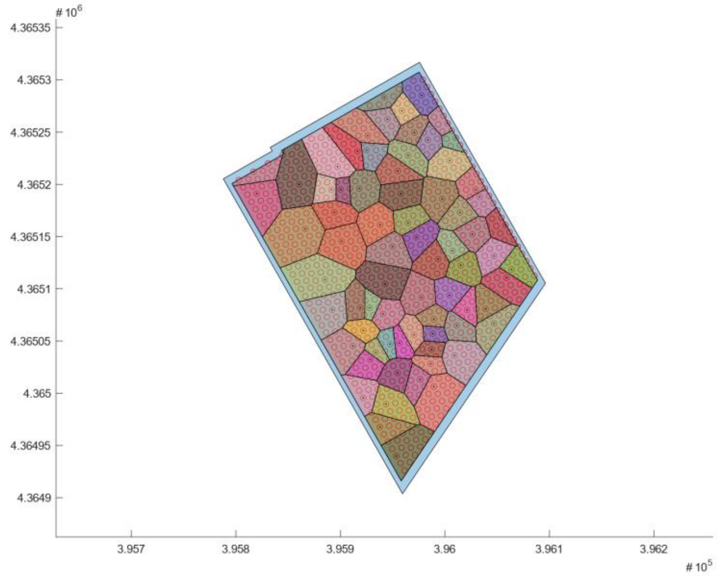

Figure 6. Weighted K-Medoids allocation of pollinators

Table 1. Allocation methods results

Method	Pollinator percentage	Mean distance to pollinator (m)	Standard deviation (m)
Empirical	25%	12.29	4.57
Voronoi	8%	10.81	4
K-Medoids	8%	11.88	3.43
Weighted K-Medoids	8%	15.47	8.48

4. Discussion

Compared to the empirical method, both methods proposed have given promising results. Taken into account that all new methods proposed have 66.67% less pollinators, they outperform empirical pollinator allocation. Voronoi and K-Medoids clustering actually performed even higher than the empirical method. Weighted K-Medoids is still performing higher than the empirical method when the percentile of pollinators is considered, however the potential of this method needs to be assessed by experimental data. Direct comparison would require to transform the other layouts to the curvilinear coordinate system and calculate metrics based on it. The weighted method was optimized on this coordinate system, which would result to all other methods being at a significant disadvantage.

5. Conclusions

To fully evaluate the comparative advantage of the weighted K-Medoids pollinator allocation method, experimental data need to be processed that will justify the comparison on the curvilinear coordinate system that this method relies on. However, the value of spatial optimization, even in the care of the weighted method, is clear. The increased number of productive trees in an orchard is a significant gain for the multiyear cultivation. Designing with the help of digital tools allows for both digital documentation of the orchard, providing downstream usability, and for dry-running layouts without the longtime commitment of applying them in practice.

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DATA TRANSMISSION AND MANAGEMENT FOR WIRELESS SENSOR NETWORKS IN GERMAN DAIRY FARMING ENVIRONMENTS

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ABSTRACT

The intensity of animal husbandry rises, as well as the regulation and documentation requirements every farmer must fulfil. Wireless Sensor Networks (WSN) are an option to improve efficiency and animal welfare on dairy farms. They provide information, that helps farmers to focus on the necessary chores and help automate documentation and control processes. However, a dairy farm is a difficult environment for wireless data transmission. This research shows the most common connectivity options in Germany and discusses the technologies regarding their usefulness for data transmission on a dairy farm. It is shown, that the digital transformation of a dairy farm requires different network technologies for different tasks. Data Management must integrate seamlessly and provide decision support as well as control over the farmer's data. A powerful middleware based on broker models can be a solution to bring together live sensor data and information from existing information systems. The digital twin model of the dairy research station of Technical University of Munich is shown, as example for the visualization of a custom user interface (UI). Intuitive UIs are needed for a successful adoption of the technology by farmers.

Keywords*:* Digital Transformation, Agriculture 4.0, Connectivity, IoT, Animal Husbandry

1. INTRODUCTION

In Germany, the intensity of crop farming and animal husbandry rises. However, German farms are still very small in international comparison. Many farmers produce high quality products tailored to several niche markets accompanied by documentation and traceability issues. Farm management information systems are on the rise to help farmers cope with the complexity of these very diverse production systems. In this context, an innovative approach for dairy farming is under development, the "Integrated Dairy Farming" project (Stumpenhausen et al., 2018), which is part of the precision dairy farming concept (KTBL, 2007). One part of the concept is to support the farmer by providing a digital real time model of his dairy and animal production system. The data needed for this information system is combined information out of existing documentation systems, paired with data from wireless sensor networks (WSN) on the farm. All the information available is pre-processed by a powerful middleware and displayed in a customized user interface (UI). Already in the early nineties, it has been recognized, that in order to run such a complex system, the failsafe and error-free transmission of

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sensor data must be guaranteed under adverse conditions found on farms (Schön, 1993). Today, there is the need to transmit, collect and process information out of different existing information systems and merge this data into one central system. Therefore, data transmission in this paper shall not only resemble the transmission technology used to transfer data from point A to point B but shall also reflect on the ability of smart systems to connect to each other automatically.

2. Methodology

The methods used are threefold. First, available transmission technologies, frequencies, standards and protocols are identified and compared, like for example WiFi and LoRa WAN etc. They are discussed regarding their benefits and shortcomings for agricultural use in a dairy stable environment. As a second step, qualitative expert interviews with four farmers from southern Germany, that already have gathered first-hand experience from using wireless sensor networks, are carried out. Their needs, wishes, and experiences are identified. In a third step, experiences from digitally transforming the dairy research station of the Technical University of Munich, where the concept of a digital real time model of a dairy farm has already begun to be implemented, are taken into consideration as well.

3. Results

3.1. Comparison of important connectivity options

Table 1 shows an excerpt of the analysed connectivity options and their technological differences.

Table 1. Comparison of the most commonly available Connectivity Options for Wireless Sensor Networks in Agriculture (own research)

Wireless technology	Frequency	Maximum Data rate	Maximum Range	Penetration	Energy consumption
Mobile communications (GSM – 5G)	700/8001800/ 2600 MHz	150 Mbit s^{-1} - 20 Gbit s^{-1} (5G)	35 km	low	high
WiFi	1,4/3,6/5,8 GHz	600 Mbit s^{-1}	30 m -100 m	low	high
Bluetooth	2,4 GHz	2,1 Mbit s^{-1}	100 m	low	medium
Bluetooth LE	2,4 GHz	125 kbit s^{-1}	40 m	low	medium-low
LoRa	868 MHz	0,3 – 50 kbit s^{-1}	5-10 km	high	low
Sigfox	868 MHz	0,1 kbit s^{-1}	5-10 km	high	low
Zigbee	868 MHz 2,4 GHz	20 kbit s^{-1} 250 kbit s^{-1}	1500 m 10-20 m	high low	low

There are two important categories. First, conventional connectivity technologies, such as for example mobile communications networks (Miki et al., 2005), WiFi and Bluetooth (LE). These technologies are easy to use and implement, because the hardware is already widely available on a plethora of mobile devices. Second, there are the so called "narrowband IoT" options (Mekki et al., 2018), such as for example LoRa, Sigfox or Zigbee. These options usually offer increased range, penetration and reduced power consumption (Raza et al., 2017). In return, they sacrifice data rate and convenience, and the network infrastructure usually has to be supplied by the end user for agricultural applications.

For the decision of which connectivity option to choose for a sensor network, additional criteria must be taken into consideration (Ried, 2018). For example, costs for hardware and running costs for service providers, the building structures on site (concrete walls, roofs, metal fencing, distance and orientation of buildings) and the energy supply concept for the sensor network (batteries, direct power supply or energy harvesting concepts, lightning protection).

Table 2 shows examples for use cases regarding the aforementioned connectivity options and their potential for transmission of sensor data in a dairy stable environment.

Table 2. Wireless data transmission technologies and examples of use cases in a dairy stable environment (own research)

Wireless technology	Suitable for	Distinct advantage	Example dairy-farm use-case
Mobile communications (GSM – 5G)	Long range – high data rate application	Service provider offers network	Tail mounted calving sensor (even on remote pastures)
WiFi	Short range – high data rate applications	Cheap infrastructure Minimal running costs	IP-camera for calving area
Bluetooth	Short range, high data rate peer to peer connection of end-devices	Technology widely available in existing end-devices	Remote control of slat cleaning robot
Bluetooth LE	Low energy medium data rate applications with multiple devices	Lower power consumption than conventional Bluetooth	Mesh configuration of regurgitating & movement sensors
LoRa	Long-range low energy low data rate applications	Easy to install own network structures, good penetration, long range	Cow tracking on mountain pasture
Sigfox	Indoor and long-range outdoor proprietary sensor systems	Wide array of out of the box sensor systems	Monitoring milk chamber temperature
Zigbee	Indoor automation tasks	Wide array of available actuators from the "smart home market"	Lighting & Energy management, smart locks

The research shows, that the diverse conditions on dairy farms make it necessary to use different connectivity solutions for different tasks. The tables above show the most important decision criteria, when deciding which connectivity option to use for a specific use case. In a dairy farming environment special attention must be paid to robustness of the hardware, penetration of building structures and data transmission to remote areas with minimal power consumption.

3.2. Needs, wishes and experiences of farmers

The farmers agreed, that the use of WSN offers potential for increasing animal welfare and productivity increase. However, they admonish, that the market is dominated by proprietary systems, what forces them to use multiple applications and programs on their end devices. This is a great hindrance for convenience and productivity. Data management and exchange between sensor-system-applications and already existing documentation systems does not work well. Sharing data between systems and along the value chain is a problem, causing a lot of time loss. This is backed by the research of Jungbluth et al. (2017). Some of the systems they have gathered experiences with, don't provide intuitive user interfaces, which is a problem for new or seasonal workers. Some of the farmers wish there was an across systems data management approach, which would facilitate their daily work with these information systems. To improve the situation of farmers and further unlock the potential of WSN in agriculture, the use of these systems must be made as convenient as possible for the farmer. As farmers face more and more documentation chores in their daily work, the automation of data generation, processing and sharing is important. Farmers need intuitive user interfaces and decision support, but also want the option to access raw data, manage data storage options and change or regulate automated decisions made by smart systems.

3.3. Experiences from WSN-use on the research farms

Experiences from using WSN on the dairy research farm of TUM show, that in practice, the range, data rate and penetration of the different connectivity options stay far behind the promises made in the technical specifications charts. This is mainly due to the adverse conditions found on a dairy farm. In international comparison, further problems arise due to the spatial availability of specific frequency bands, e.g. 433 MHz is implemented in the LoRa stack in the USA but not available to use for LoRa-based WSN in Germany. Another important factor are the dairy cows themselves. Their urge to play with sensor hardware and move erratically leads to the need for very robust sensors and network topologies. Especially in research, many use cases are close to breaking the duty cycles of certain protocols, an important factor to take into consideration, as regulation and control of this matter rises. The biggest problem after all, is the harmonization of different protocol stacks, bus systems and general data management, which is hard to integrate into one central system.

4. Discussion – Broker model

The introduction of digital broker models as a powerful middleware to preprocess and route data as well as offer a custom visualization of the data and historicization process, can be a solution to the problems mentioned above. It even offers the addition of a control layer, where actuators can be integrated to the system and linked to the WSN and other systems through a cyber-physical systems approach (Broy, 2010). Figure 1 shows the custom user interface of a broker model implemented at the chair of agricultural systems engineering of the TUM. It is based on open-source software for home- and industrial automation (ioBroker GmbH, 2019). The model aims to digitally transform the research farms of TUM. In Figure 1, the overview section of the WSN on the research dairy farm is shown. In this view, sensor nodes and systems are shown as colored circles. If all circles are green, no action is necessary, and all systems operate within their boundaries. If problems arise, the farmer is informed by a pop-up notification and can then access detailed information and graphs of the individual sensor systems. It is even possible to actuate simple actors like switches, doors, lights, valves and locks. The structure of the user interface is modular.

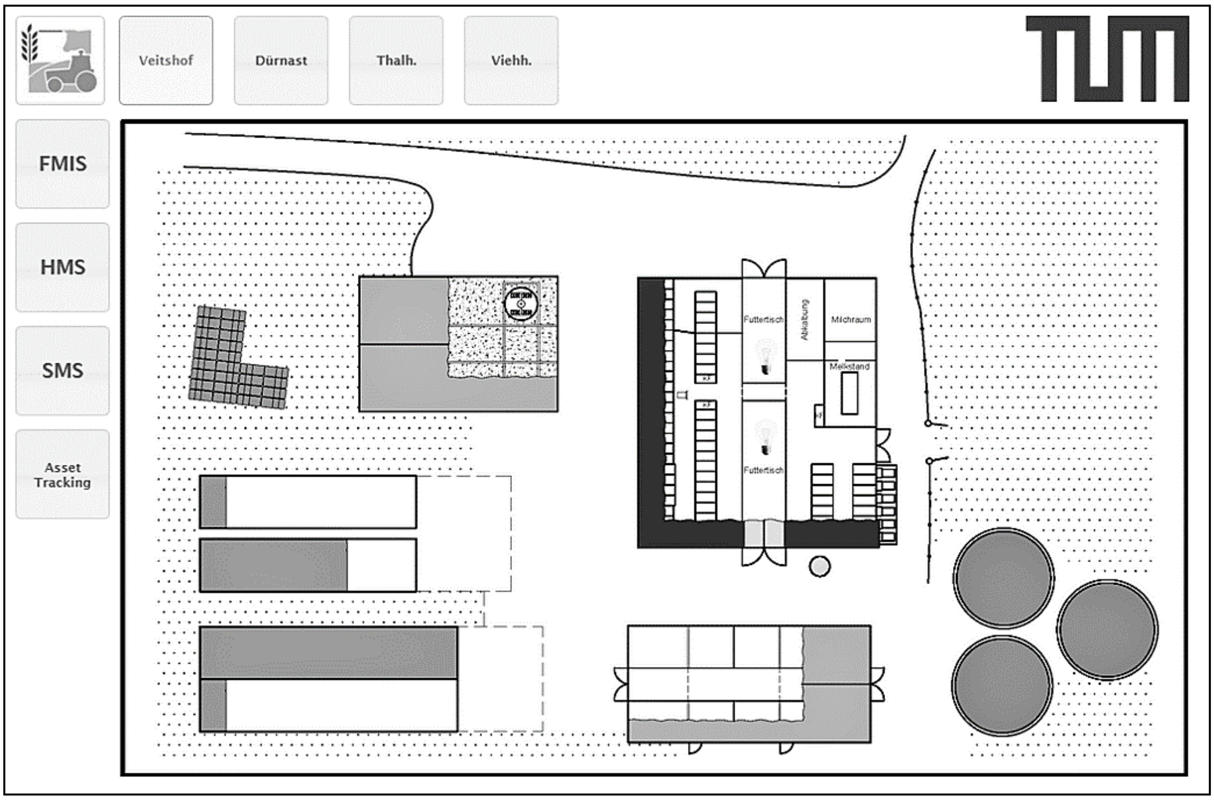

Figure 1. Custom User Interface combining live sensor data and information from documentation systems

The top buttons show the different research farm locations (Veitshof, Dürnast, Thalhausen and Viehhausen), while the logo in the top left represents a home-screen where information from external data providers like milk or diesel prices, as well as weather forecasts can be displayed. The buttons on the left offer access to further functionalities like asset tracking (e.g. tractor location), storage management system (SMS, e.g. grain silo temperatures and humidity), herd management system (HMS, cow-tracking, health and fertility monitoring) and the farm management information system (FMIS, digital documentation, crop farming etc.). The broker model can integrate live information from the installed sensor networks over a wide variety of connectivity options. Like this it is possible to link proprietary sensors and actors like zigbee hardware and integrate self-made systems based on open source technology like Arduino microcontrollers or raspberry pi single board computers with cheap sensor hardware. The broker model itself is running on a single board computer in server configuration and can also implement an access management for different user groups. The model is a work-in-progress project and will be enhanced and have further functionalities added to it for research and teaching purposes. Once completed, it will enhance the accessibility of data for researchers, and offer the opportunity to discover new dependencies in the processes of a dairy farm.

For the Model to be successful, APIs and adapters for different data protocols are essential. A further standardization regarding sensor data frameworks is desirable and should be noticed by the manufacturers of dairy farming equipment. A wide adoption of these models by farmers seems unlikely now, because of the complexity and time consumption to build these systems. A modular approach by external service providers, may help to make these systems available for farmers in the future.

5. Conclusions

Dairy Farms in Germany offer adverse conditions for the wireless transfer of sensor data, as there are long distances, concrete buildings, metal fencing, large rooftops and problems in energy supply that must be overcome. Therefore, different connectivity options are needed for different tasks.

Farmers recognize the benefits WSN offer for their daily work and animal welfare. However, they wish for more convenient solutions, easier documentation and more compatibility between systems. Digital Broker models offer the functionalities to overcome the limitations of connectivity today and should be investigated for agricultural use. Building a broker model for agricultural use is a complex and time-consuming process, hindering fast adoption. However, in the future, further development of sensor data standards (e.g. OGC) and APIs (e.g. for milking robots and automatic feeding systems) as well as a modular approach by software service providers, could make this technology accessible for farmers. This would offer them the custom, platform-independent information system for their individual farming business, that they desire.

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SEDIMENT WATTLE CONFIGURATION AND OPTIMIZATION OF PASSIVE POLYMER APPLICATION FOR TURBIDITY REDUCTION IN CHANNELIZED RUNOFF

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ABSTRACT

Effects of accelerated erosion resulting from such anthropogenic land disturbing activities as agriculture, timber, harvesting and construction are numerous and well-documented. In addition, elevated turbidity from eroded soil has gained recognition as an indicator of sediment associated impairment to water quality. Previous research has shown that passive polyacrylamide (PAM) can be effective in reducing soil erosion when applied to irrigation water in agricultural settings. Water soluble anionic PAM was identified as highly effective at preventing erosion and increasing infiltration when used with furrow irrigation. The focus of this research was to maximize turbidity reduction within channelized flow using passive polyacrylamide (PAM) applications in association with excelsior fiber sediment wattle installation. Four treatments were applied to assess various PAM application methods including; (i) a control with no PAM; (ii) granular PAM applied in 100-g doses directly on each of five sediment wattles before five simulated runoff events; (iii) granular PAM applied in 100-g doses directly on each of five sediment wattles only once before five simulated runoff events; (iv) granular PAM held in a permeable bag applied with 500-g doses. Results provide evidence that PAM application can be an effective practice for turbidity reduction within channels. Sediment wattles without PAM application provided no reduction in turbidity (F-stat = 0.0588, p = 0.9975, n = 60). Passively applied PAM was greatly more effective in reducing turbidity than the evaluated permeable PAM bag. Mean turbidity, over five simulated runoff events, was 202 NTU using three sediment wattles when PAM was applied. This research provides considerable evidence that highly turbid, sediment-laden channelized site runoff can be remediated using passive granular PAM application and sediment wattle installation.

Keywords: erosion, polyacrylamide, PAM, simulated runoff, best management practices, wattles

1. INTRODUCTION

Because sediment pollution can result in significant environmental impacts, federal and state agencies actively regulate total suspended solid (TSS) in construction site discharge. TSS is comprised of inorganic solids, sand, silt, clay sediment particles, and organic solids, algae and detritus. As a surrogate parameter, turbidity is gaining recognition as a regulated indicator of pollution associated with sediment-laden discharge from construction activities. Turbidity is a measure of optical properties associated with water clarity. Turbidity measurements are easily obtained and can provide an accurate estimation of fine sized soil particles transported by runoff.

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Research shows that common structural best management practices (BMP) such as sediment basins, can meet design specifications but still cause elevated turbidity levels (Line and White, 2001; Wu et al., 1996). Traditional sediment basins often provide inadequate settling times for clay-sized particles. Such smaller particles can be resuspended during rain events and ultimately discharged off site. Temporary erosion control devices such as rolled erosion control products (RECPs) and polyacrylamide (PAM) dosing have demonstrated effectiveness in reducing suspended sediment and turbidity (McLaughlin and McCaleb, 2010).

This research evaluated sediment wattle configuration with passive PAM application for optimized turbidity reduction. Specific objectives included examining sediment wattle configuration, PAM application and polymer desiccation between runoff events.

2. METHODOLOGY

A 56.4 m triangular channel, 3.66 m wide with an average depth of 0.50 m, at a 7% slope was constructed and lined with 50-mil high-density polyethylene HDPE. The channel was lined to prevent scouring and erosion, which might affect turbidity during experimentation and potentially compromise results. Ditch checks were deployed with 508 mm diameter American Excelsior Curlex® sediment wattles (AEC, 2012). Sediment wattles were installed within the channel at 7.62 m intervals following South Carolina Department of Transportation (SCDOT) specifications (SCDOT, 2011). Based on channel length, five sediment wattles were used in series.

To determine an experimental flow rate, 1-yr, 24-hr rainfall events were averaged for Greenville, Richland, and Charleston counties in South Carolina, USA. The peak flow from the average 1-yr, 24-hr rainfall depth (86.6 mm) over a newly graded 0.404 ha site at a 2% slope is 0.07 $m^3 \cdot sec^{-1}$. An 18.2 m^3 collapsible tank was selected to simulate runoff and produced a peak discharge rate of 0.05 $m^3 \cdot sec^{-1}$ with an average flow rate of 0.02 $m^3 \cdot sec^{-1}$.

A sediment-laden solution was needed to simulate runoff from a construction site. A naturally occurring kaolinite clay was selected to represent the silt/clay fraction found in a regional Piedmont soil. An 8200 watt pump with a flow rate of 20 l sec^{-1} was used to recirculate the tank solution. Initial turbidity in the tank ranged from 1,600 to 2,000 nephelometric turbidity units (NTU) and was measured by an Analite NEP160 display with NEP260 probe handheld turbidity meter (McVan, 2012).

Six automated ISCO 3700 units were deployed for sample collection. Liquid detectors activated the sampler routine comprised of 4-minute intervals and continued until channel flow ceased. Intake strainers were placed directly at the tank outlet and on the downstream side of each wattle. Samples were analyzed using a Hach 2100AN turbidimeter following Standard Method 2130 B (APHA, 2005).

Three polymer application treatments were evaluated using the experimental methods described below:

- Treatment 1. 100-g of polymer sprinkled directly on each of the five sediment wattles and reapplied each time prior to five simulated runoff events.
- Treatment 2. 100-g of polymer sprinkled directly on each of the five sediment wattles applied only once before five simulated runoff events.
- Treatment 3. 500-g of polymer in a 15.24 cm x 61 cm smooth weave 400 micron permeable bag placed on the tank outlet and the downstream stream side of each sediment wattle.

Each run simulated a single runoff event and consisted of draining one full tank as described above. Each treatment consisted of five separate runs completed within a 24-hour period. All procedures were duplicated for statistical accuracy. Following each treatment, wattles were discarded, channel cleaned, and excess sediment accumulation within the tank was removed.

Statistical methods to quantify results include regression analysis, analysis of variance, and t-tests. An alpha value of 0.05 is used and all statistical calculations were performed with SAS JMP software.

3. RESULTS AND DISCUSSION

3.1 Analysis of Application Techniques - A JMP model using analysis of variance (ANOVA) and paired t-testing was developed to assess response of mean turbidity across runs and sample locations. Simple means testing within each treatment quantified the degree to which a change in turbidity resulted from each PAM application technique. The sample location for tank outlet, sediment wattle 1, sediment wattle 2, sediment wattle 3, sediment wattle 4, and sediment wattle 5 will be referred to as L0, L1, L2, L3, L4, and L5, respectively (Figure 1).

Figure 1. Channel layout schematic

3.1.1 Control - Control results where no polymer was applied suggest a significant difference in mean turbidity between runs. ANOVA results show an increase in mean turbidity over 5 runs (F-stat = 10.4867, p< 0.0001, n = 60). Such an increase in turbidity across runs may be attributed to accumulation and resuspension of settled clay particles within the tank. To assess whether reductions occurred across sample locations, mean turbidity values were then used for all runs. Mean turbidity discharged at L0, L1, L2, L3, L4 and L5 was 3276, 3098, 3162, 3126, 3213, and 3105 NTU respectively. F –test results revealed mean turbidity across sample locations (F-stat = 0.0588, p = 0.9975, n = 60) was not significantly different (Figure 2). Simple means testing further indicated there were no statistical differences in turbidity values across sample locations. Had sediment wattles created any measurable reduction, turbidity values would have been statistically different across sample locations. The lack of turbidity reduction in the control experiments suggest that sediment wattles alone are ineffective at reducing turbidity. While cumulative turbidity percent reduction values may visually appear to suggest a slight reduction, results show no statistical difference (p = 0.9817).

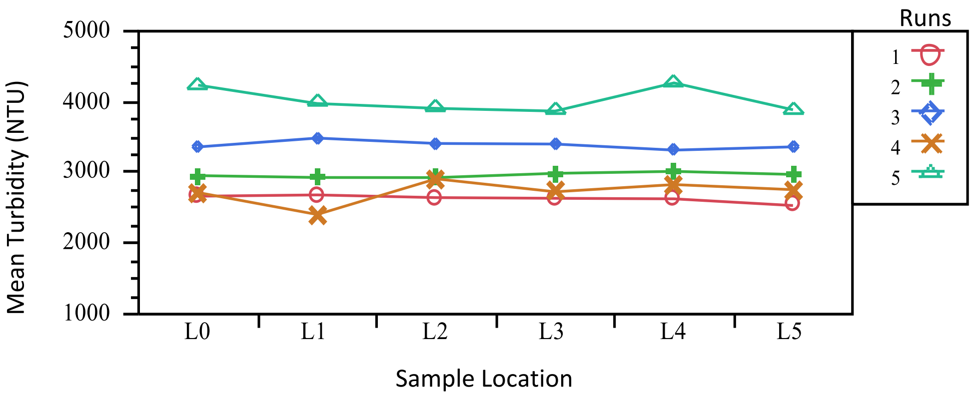

Figure 2. Mean turbidity by run across sample locations for control experiment.

3.1.2 Treatment 1: Repeated PAM Application - To test various PAM application methods, Treatment 1 applied 100-g granular APS #705 PAM to each of five sediment wattles before each run. ANOVA results failed to show a difference in mean turbidity over all 5 runs (F-stat = 0.3720, p= 0.8266, n = 60). Across sample locations, results further revealed that mean turbidity (F-stat =246.95, p = <.0001, n = 60) was significantly different. Additionally, t-test results show a significant difference in mean turbidity across locations L0, L1, and L2 but failed to find a significant difference between locations L3, L4, and L5. These results suggest a statistically significant decrease in mean turbidity is achieved with only three sediment wattles in series as shown in Figure 3.

Utilizing five sediment wattles, a mean cumulative reduction of 96% turbidity is was achieved. T-test results indicate a significant difference in mean turbidity percent reduction across locations L1, L2, L3, and L5. These results can subsequently be used to determine the number of sediment wattles needed in a treatment series for optimized turbidity reduction.

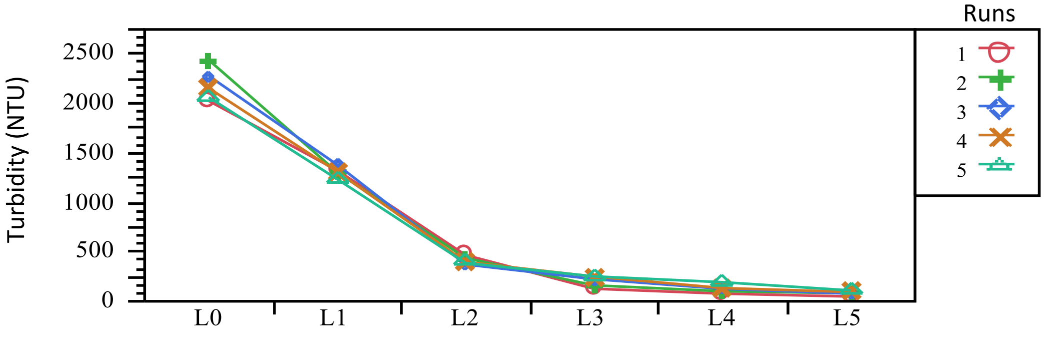

Figure 3. Turbidity across sample locations for each run within Treatment 2.

3.1.3 Treatment 2: Single PAM Sprinkle - To evaluate the potential effectiveness of a single PAM dose, 100-g granular APS #705 PAM was sprinkled on each of five sediment wattles before an initial run and not applied again prior to subsequent runs. ANOVA results show a difference in mean turbidity across runs (F-stat = 5.0713, p = 0.0044, n = 54) with follow-up t-tests suggesting run 4 was higher than runs 1-3. The increase in turbidity associated with run 4 may be attributed to a buildup of settled clays within the mixing tank during the course of experimentation. Analysis of variance revealed that mean turbidity across sampled locations was significantly different (F-stat = 114.60, p <.0001, n = 54). T-test comparisons show a statistical difference between sample locations L0, L1, L2, and L3 (p<0.0001). Results therefore suggest if only a single dose of PAM is applied, then a minimum of four sediment wattles is necessary to achieve maximum reduction (Figure 4).

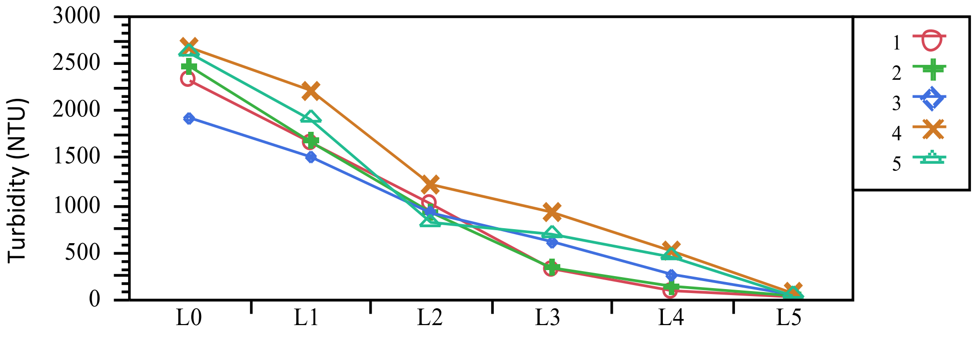

Figure 4. Turbidity across sample locations for each run within Treatment 2.

Mean turbidity reduction at location L5 is 97%. Based on t-test results, observations at all locations were significantly different (p<0.0001), indicating turbidity reductions were occurring at each sediment wattle.

Results from Treatment 2 further support the effectiveness of PAM application for turbidity reduction in sediment-laden runoff. Single dose PAM application runs had an average turbidity of 61 NTU and mean reduction was 97%.

3.1.4 Treatment 3: PAM Bag - ANOVA results show a significant difference in mean turbidity across runs (F-stat = 8.5054, p = 0.0001, n = 58), which suggests a decrease in effectiveness of the PAM bag application over time (Figure 5). F–test results revealed that mean turbidity across locations (F-stat = 48.4705, p<0.0001, n = 58) is significantly different. T-test comparisons show no statistical difference for sample locations L1 and L2 and between L3, L4 and L5. Mean turbidity discharged from sediment wattle 5 was 915 NTU. Cumulative turbidity percent reduction achieved for Treatment 3 was 71%.

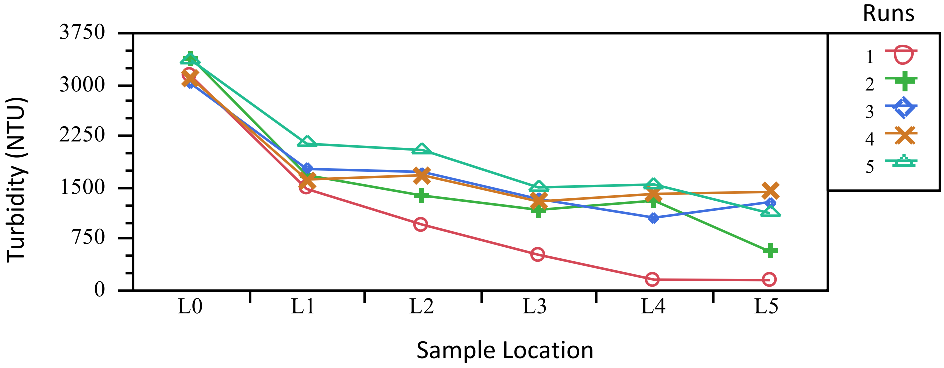

Figure 5. Turbidity across sample locations for each run in Treatment 3.

Figure 5 suggests the PAM bag losses efficacy after only a single run. Turbidity measured at the terminal point of Run 1, at L5 was 152 NTU. After Run 1 it was observed that the granular PAM had swelled and became a cohesive gelatinous mass. By Run 5, discharged turbidity at the same location had increased to 1127 NTU. While clearly effective for a single run, such an increase in turbidity across multiple runs suggests the use of such a PAM bag in channelized flow would be ineffective over time.

3.2 Comparison of Treatments - ANOVA and t-tests were conducted to determine whether turbidity values from each treatment were different. Figure 6 shows mean turbidity for all treatments across sampled locations. ANOVA results show a difference in mean turbidity across sample positions within treatments (F-stat = 37.7199, p<0.0001, n=232). Results did indicate a significant difference (p <.0001) in mean turbidity at location L5 between the Control (3104 NTU) and Treatment 3 (915 NTU). Additionally, mean turbidities for Treatments 1 & 2 were statistically lower (p = 0.0002) than those for Treatment 3. T-test results failed to show a difference (p = 0.9253) between mean turbidity values at location L5 for Treatment 1 (82 NTU), and Treatment 2 (61 NTU), suggesting little resulting difference between these two PAM application techniques.

T-test results comparing percent reduction found no significant difference (p = 0.8156) between Treatment 1 and Treatment 2 at location L5. Results did show a significant difference (p<.0001) in percent reduction across locations L2 and L3 for Treatment 1 compared to Treatment 2. These results suggest Treatment 1 creates a more rapid reduction in turbidity than the other test treatments, thus requiring fewer wattles and lower BMP costs.

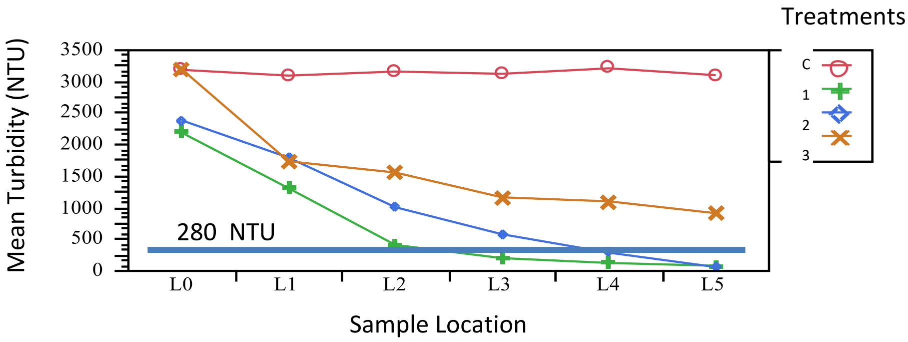

Figure 6. Comparing mean turbidity across sampled locations for each treatment.

4. Conclusions

The objective of this research was to reduce turbidity using passive PAM application techniques by optimizing wattle configuration in simulated construction site runoff. The following conclusions can be summarized from the results.

1. Under simulated conditions, sediment wattles alone provided no reduction in turbidity.
2. PAM applied before each run (Treatment 1) decreased turbidity to target levels using fewer wattles than PAM applied only once (Treatment 2) before all runs.
3. Turbidity levels meeting the proposed EPA 280 NTU effluent limit were achieved after 3 sediment wattles when PAM was applied before each run.
4. While PAM applied once did ultimately achieve target turbidity levels, this application technique required five sediment wattles.
5. PAM bag deployment technique did not result in target turbidity levels beyond the initial run.

This research suggests passive polymer treatment may be necessary to meet nationally promulgated turbidity standards for construction site discharge. Of those techniques assessed, granular PAM applied directly to excelsior wattles resulted in the highest turbidity reductions by providing a large surface area for interactions with small clay particles. Even using polymer application techniques described here, fine clays and flocs that temporarily settle behind wattles are resuspended and mobilized with each simulated runoff event, suggesting that regular maintenance of wattles may be required to consistently achieve target turbidity levels in site discharge.

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ASSESSING AGRICULTURAL SUSTAINABILITY WITHIN A FARM MANAGEMENT INFORMATION SYSTEM: A REVIEW OF INDICATORS

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ABSTRACT

The use of Farm Management Information Systems (FMIS) is spreading over the last years facilitating operational management leading to increased productivity while minimizing the relevant production costs. FMISs use indicators in order to benchmark the performance of a cultivation usually in terms of its economic return and its environmental impact. However, these are mostly standalone indicators that are not combined and holistically examined towards the determination of an agricultural system's overall sustainability. It is also very important to note that the assessment of agricultural sustainability has been a continuous debate within the scientific community and still a commonly used methodology has not been established. Several methodologies and frameworks have been employed most of which use sets of indicators to assess the economic, environmental and social impacts of agricultural operations. Attempting to address the issue of sustainability benchmarking within a FMIS this paper presents a literature review of sustainability indicators that are used in agricultural sustainability studies at farm level. A total of 36 studies were thoroughly examined in order to extract the individual economic, environmental and social indicators that were employed. The indicators were categorized depending on the examined theme and a frequency analysis was conducted in order to determine the most frequently used. Ultimate goal of the review is to arrive at an easily computable and comprehensible system of indicators that could be used in a Farm Management Information System providing the stakeholders with integrated information regarding the overall sustainability performance of their cultivations.

Keywords*:* Farm Management Information System, agricultural sustainability, indicators, review

1. INTRODUCTION

In recent years the use of agricultural production management tools has become widespread. The need for management of farming practices has become essential especially due to the intensification of agriculture in order to meet the increasing food and energy demand (Rodias *et al.*, 2019). Nevertheless, this intensification is linked to a plethora of impacts related to the environmental, economic and social aspects of agricultural production that are associated with the excessive use of plant protection substances, fertilizers and water as well as with changes in land use (Bockstaller *et al.*, 2009) which put the sustainability of the practices used into question (Rodias *et al.*, 2017). In the case of agricultural sustainability, no definition, universally accepted by the scientific community, has been formulated yet. However, in order to assess sustainability in its entirety all three pillars of

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sustainability, namely the environmental, the economic and the social, should be addressed (Pham and Smith, 2014; Banias *et al.*, 2017; Lampridi, Sørensen and Bochtis, 2019).

Considering the above, the integration of sustainability assessment into the process of agricultural production management becomes of particular importance (Marinoudi *et al.*, 2019). Regarding the assessment of agricultural sustainability a large number of methodologies and tools have been developed (Cerutti *et al.*, 2011). There are tools that have gained the general public acceptance such as Life Cycle Assessment (LCA) which is standardized with ISO (De Luca *et al.*, 2015). Additionally, several methodologies and tools have been proposed that mainly employ indicators for evaluating the sustainability of an agricultural system (Gómez-Limón and Sanchez-Fernandez, 2010). To that end, the standardization of sustainability assessment methodologies for agricultural practices is a complex task as it includes many methodologies and variables that vary on each case study (Lampridi *et al.*, 2019). The situation becomes more and more complex when trying to integrate such tools into a Farm Management Information System (FMIS) (E. Rodias *et al.*, 2017).

For this reason, the purpose of this paper is to investigate the indicators used to evaluate agricultural sustainability based on an extensive literature review and identify those that could be used within a FMIS. A total of 36 studies were thoroughly examined in order to extract the individual economic, environmental and social indicators that were employed. The indicators were categorized depending on the examined theme and a frequency analysis was conducted in order to determine the most frequently used. Ultimate goal of the review is to arrive at an easily computable and comprehensible system of indicators that could be used in a FMIS providing the stakeholders with integrated information regarding the overall sustainability performance of their cultivations.

2. METHODOLOGY

The review process that was followed for the identifications of the indicators that could be integrated in a FMIS is presented in Figure 1.

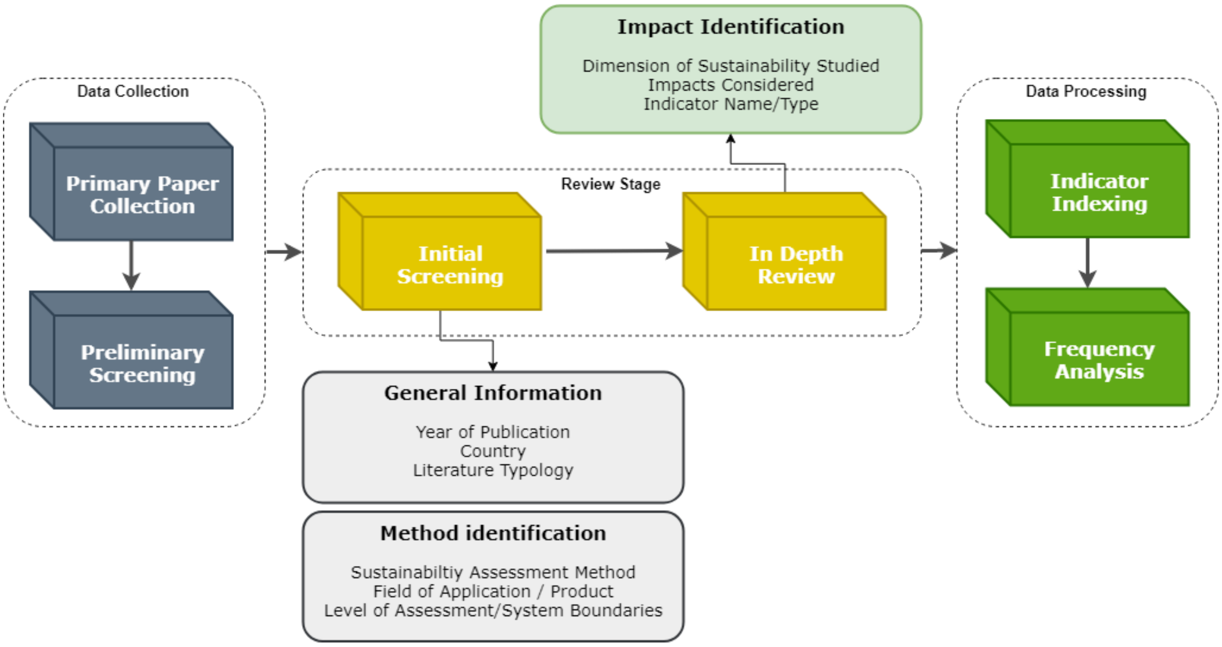

Figure 1. The Review Process

Main purpose was to systematically research the impacts, expressed as indicators, that are addressed within each of the studies that were reviewed. The review methodology includes three distinct stages, namely the data collection, the review and the data processing. The data collection stage begins with the primary paper collection. The initial sample of papers is selected through some of the most widely used scientific search engines such as the Scopus and Science Direct using a variety of appropriate key words (e.g. agricultural sustainability, Farming and Sustainability, Economic-Environmental Social Sustainability and Agriculture). With the preliminary screening the studies that did not consider all the three impacts of sustainability are excluded.

The initial screening stage concerns the classification of the papers collected based on primary criteria. These criteria include general information (Year of publication, Country and Literature Typology) and the identification of the method employed in the study. The initial screening facilitates further classification of the sample collected based on the method used, the level of assessment as well as the field of application. In that manner it is easy to determine the final sample which is then reviewed in depth in order to extract the dimension of sustainability studied, the impacts considered, and the names and types of the indicators used. During the final stage, data processing, the indicators collected are being classified according to the dimension of concern. Then the sample is reduced in size by aggregating indicators with similar context. The process concludes with the frequency analysis stage. The process includes the creation of a frequency matrix containing all the indicators and the papers that these indicators were used to assess sustainability. Indicators that have a frequency of occurrence higher than a specific threshold were included in the final indicator collection.

3. RESULTS

The application of the methodology described in the previous section resulted in a total of 36 studies published in peer reviewed scientific journals from 2009 till 2018, that assess the sustainability of crop cultivations on the farm level which were reviewed in depth. Assessments that examine sustainability at a regional or national level were excluded for the research since FMIS's are used for management at the individual farm level. The final sample was thoroughly reviewed and a total of more than 500 individual indicators were extracted concerning the three pillars of sustainability. The indicators were aggregated and classified according to the dimension studied. The indicator indexing stage resulted to a total of 130 environmental, 129 economic and 161 social indicators. It should be stated that social indicators are difficult to aggregate since they address more complex and not easily countable impacts. The following charts present the results of the frequency analysis regarding the indicators that were examined. The top 5 indicators with the most appearances, within of the studies examined, are presented. The number below the indicator represents the frequency of occurrence (number of studies).

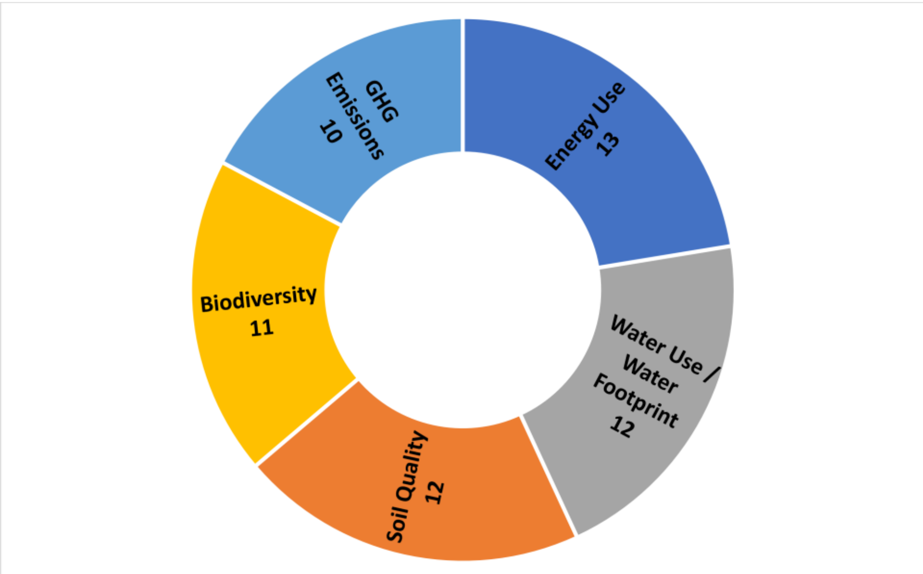

Figure 2. Frequency Analysis – Environmental Indicators

Figure 2 presents the results for the environmental pillar of sustainability. The most frequently used indicators are: energy use (appearing in the 36% of the studies), water use (33%), soil quality (33%), biodiversity (30%), GHG emissions (28%). It should be stated that indicators were aggregated based on similar context. For example energy use (Van Asselt *et al.*, 2014; Gaviglio *et al.*, 2017) was also expressed as energy management (Peano *et al.*, 2014; de Olde *et al.*, 2016).

Figure 3 presents the frequency analysis of the economic and social indicators that were extracted from the 36 studies reviewed. The most frequently used indicator is profitability (Santiago-Brown *et al.*, 2015; Snapp *et al.*, 2018) also expressed as benefit to cost ratio (Allahyari, Daghighi Masouleh and Koundinya, 2016) and return to cost (Van Passel *et al.*, 2009). Following are income (examined in 25% of the studies reviewed), efficiency (22%), productivity (19%) and yield (17%). Regarding the social pillar of sustainability most frequently indicator used is education (De Olde *et al.*, 2016) (appearing in 28% of the studies) which was also expressed as literacy (Sajjad and Nasreen, 2016) followed by health risk (19%), contribution to local employment (17%), operational difficulties (14%) and access to health (11%).

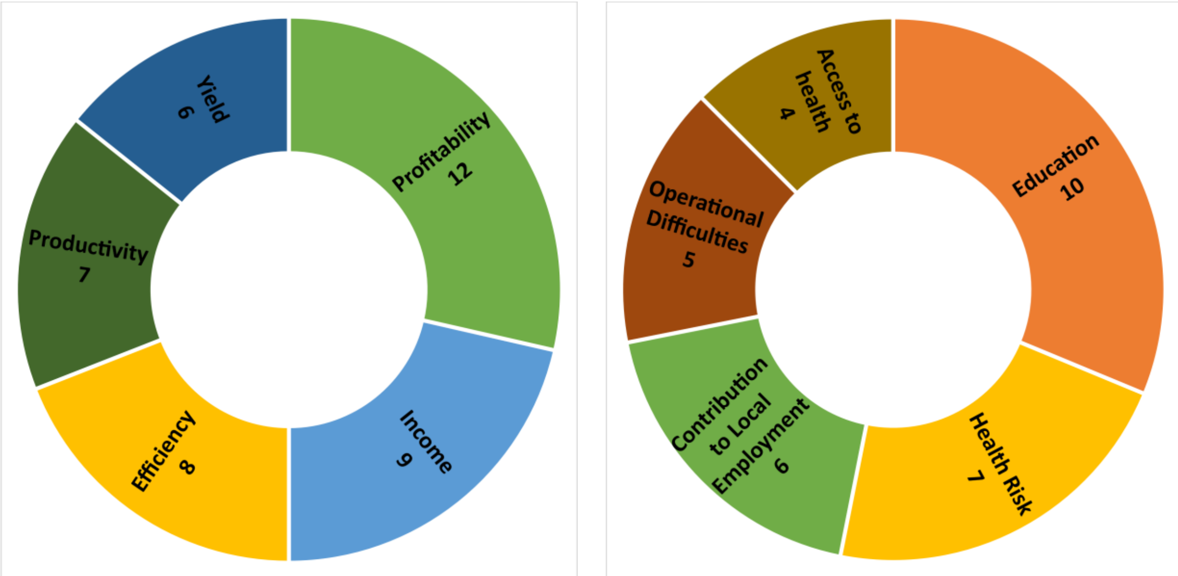

Figure 3. Frequency Analysis – Economic and Social Indicators

4. Discussion

The present study, based on a systematic literature review, attempted to propose a collection of indicators that could be integrated and used to assess agricultural sustainability within a Farm Management Information System. The final collection consists of a total of 15 indicators for the three dimensions of sustainability. The most frequently used environmental and economic indicators can be integrated easily in the context of a farm management tool since most of them can be calculated from data drawn directly for the agricultural practice performed, requiring little or no further measurements transformations and calculations, as for example for soil quality. However, social indicators are more challenging and controversial since they are expressed in many different ways making them difficult to aggregate and classify. It is a fact that social impacts are difficult to standardize and quantify due to their different perception and translation into an indicator making it an interesting subject for further elaboration and research.

Acknowledgements

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REQUIREMENTS FOR AUTOMATIC FEEDING SYSTEMS IN SOUTHERN GERMAN DAIRY FARMS

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ABSTRACT

In recent years, automatic milking systems have found widespread use in southern Germany. For automatic feeding systems a similar trend is predicted. In an online survey, the technological and structural needs of farmers were analysed. It is revealed that the current situation and the desired situation on farms about feeding times differ from each other, which is a driving force. Most farmers feed twice a day (43%), fewer once a day (29%). 34 % of the respondents consider feeding four times a day and 31 % feeding three times a day as meaningful. It turns out that especially the technical reliability and safety for humans and animals are the “absolute priority” or “very important” for 92% bzw. 75%. Not a single respondent choose “undetermined” or “unimportant”. The first economic related priority is time savings. It shows that most people are not very familiar with automatic machinery and need to build up trust first, in advance to the known economic benefits.

Keywords*:* automatic feeding systems, smart dairy farming, South Germany***.***

1. INTRODUCTION

Automation is playing an increasingly important role in dairy cattle farming (Ordolff, 2001). Automatic milking systems (AMS) have become widely used in recent years. The main reasons given by the farms were the cutting of work peaks and the flexibilisation of work. Thus, it is understandable that feeding as the next working block will now be the focus of automation (Oberschätzl-Kopp, 2016).

It is interesting that hereby a development from the twenties of the last century is taken up again. Feed is provided to the cows via crane or conveyor systems from high or low silos. The still existing 1930 GDR (German Democratic Republic) type systems partly use their automated belt feeding systems until today. From the 1960s, however, the trend went away from automated feed systems for dairy cows in Western and Southern Germany because the safety of the sampling systems was not always optimally guaranteed. They were replaced by silo and silo cutter and later by silo and feed mixer (Eichhorn, 1985).

The automatic feed systems (AFS) currently available on the market can be divided into several automation levels (Oberschätzl, 2015; Bernhardt, 2019). The easiest level is the food pusher. Here, the feed is still provided with conventional technology but the regular refeeding is done via a corresponding robot. The feed can also be mixed up once again or an additional attraction effect can be achieved by additional concentrates. As a result, the worker is only bound to the feeding times and

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the post-shift times distributed throughout the day are automated. The next level is feed distributors. The feed is provided in a feed centre. At the feeding times it is mixed and distributed. Either mixing and distributing is done in one engineering unit, or if more amount is needed per time, mixing and distributing are done in separate units. Most of the distribution units are steered over rails or tracks, whereby they are mostly used in newly built stables. In recent years, autonomous systems without permanently installed control systems are used in the barn. By adding manual control units, these can also be used in old buildings. In this second automation level, the worker is needed only for transferring the feed to the feeding centre. Depending on the storage time of the feed, this work only occurs between once a day and every five days. In between, the employee is responsible only for control and management, which he can flexibly divide accordingly (Douphrate, 2009).

In order to exclude the possible spoilage of the feed by the intermediate storage in the feeding centre, AFS are also recently offered that can bring the feed independently from the storage silos. These systems are completely autonomous and thus represent the third level of automation. Here, the human labour is needed only for control and management (Kolstrup, 2013).

The aim of this study is to record the technical and specific characteristics that an AFS must meet in order to be accepted by the majority of cattle farmers in southern Germany.

2. Methodology

A questionnaire was developed for the study to examine the further interest and present knowledge in the southern German agriculture regarding AFS. The questionnaire is based on four expert interviews. The four interview partners cover the areas of practical agriculture, agricultural organizations, AFS manufacturers and scientists. There were very different points of view. All of them, however, referred to working hours, safety and maintenance. On the basis of this experience and the existing literature, a questionnaire design was developed and tested in a pretest with three farms. After the revision, an online questionnaire was developed. The "SurveyMonkey" platform was used, because it best met the requirements.

The structural objectives were that the questionnaire addresses a wide variety of farm types and guides them through the questionnaire, depending on their answers. This is to prevent the premature termination of the questionnaire by questions that are inappropriate for the farmer. The processing time was 10 to a maximum of 15 minutes, so as not to discourage farmers. The language style was adapted to the respondents. The majority of the questions were chosen in multiple-choice format, because much information can be collected with a small effort for the respondent. Corresponding blocks of information were used during the questionnaire, which served the participant as support in relation to the course of the questionnaire or as information on the current state of the art in case of ambiguity.

The questionnaire was divided into several blocks. After two introductory qualification questions, which clarified the affiliation to the investigation group, a block with general operational questions followed. Subsequently, the focus was put on the usual feeding. In the remainder of the survey, the questions relate to the techniques available on the market. It was asked for the opinion of the respondent and suggestions for improvement. Whereby, however, it was important to inform about the current state of the art in case of ignorance. In order not to frighten the respondents or to trigger negative feelings, care was taken to keep this information as short as possible and to list only the most important.

The questionnaire was active on the portal from 16 April to 6 June 2018. In order to activate the farmer target group different approaches were chosen, whereby the personal address or via known persons and Facebook were the most successful.

During the period of publication, a total of 112 questionnaires were obtained. Due to partial breakage or completion errors, partially incomplete questionnaires are also available. Over the entire questionnaire, however, the minimum answering density is 33.

3. RESULTS

The analysis of the questionnaires showed that the online questionnaire was more likely to attract farm owner or young farm managers. As a result, 86 % of those surveyed were under the age of 35 and farm owners (39 %), farm managers (25 %) or co-entrepreneurs (9 %). Related to the type of farm, 75 % were dairy farmers and the others cattle rams or other cattle. Participants share a 77 % conventional farmers and 23 % organic farmers distribution. The average farm size was 130 dairy cows, with mostly 2 performance groups, which speaks for southern German dairy farms rather for larger farms in the investigation. The farms are run by 2.5 people, most of whom are family members. The typical form of keeping is the cubicle housing and 50 % of the cows have seasonal pasture access. These values show that the target group of sustainable family-run dairy farms in southern Germany is well represented by the questionnaire.

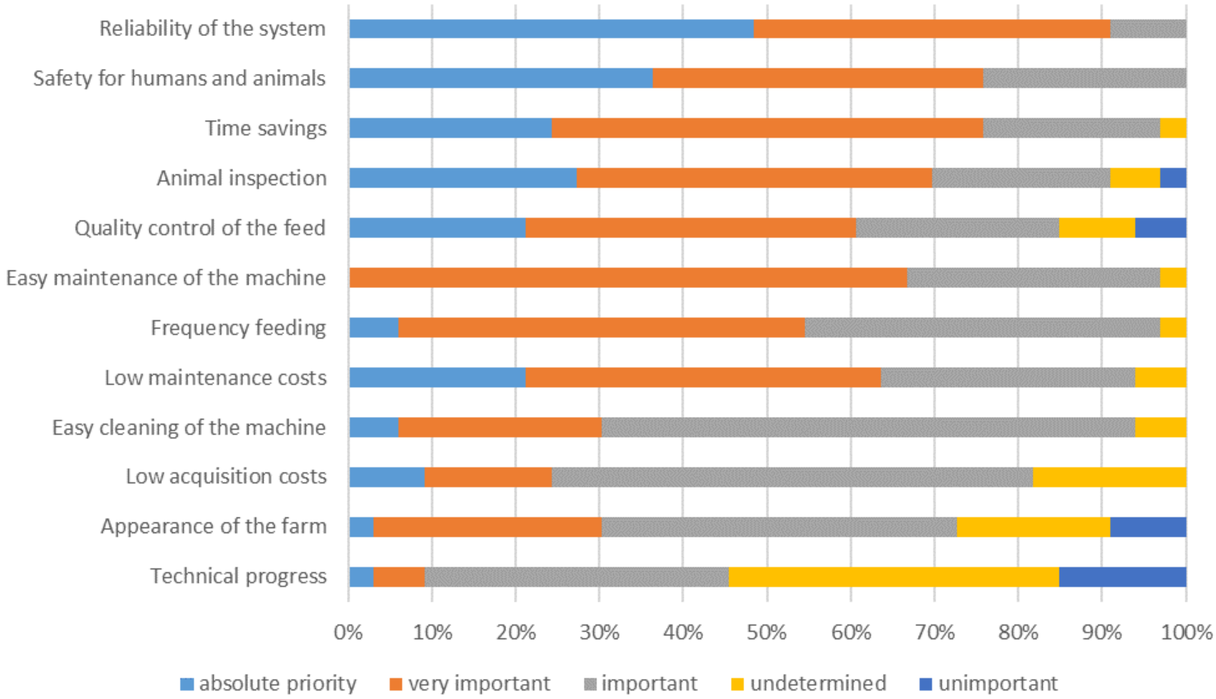

Figure 1. User requirements for automatic feeding systems

The analysis of the current feeding shows that 43 % of the famers feed twice a day, but 29 % feed only once a day. In the subsequent question about the number of feedings that are considered meaningful, 34 % of the respondents decide to feed four times a day and 31 % to feed three times. This shows that the current situation and the desired situation differ from each other. The reason for this is usually in the labour force equipment. This problem of feeding and workload is also reflected in the query of daily working hours for feeding. Here, the values vary extremely. Within the replies, values appear that can be easily classified as unrealistic by simple calculations. Such jumps in value are often a sign that no exact farm data are known. The typical feeding technique is the attached feed mixer with 47 %. In addition, self-propelled feed mixers and silo block cutters are used.

The second part of the questionnaire deals with the topic of automation at the farms. In 45 % of the farms, there is no automation, 25 % have an automatic milking system, an automatic manure gate and / or an automatic feeder.

At the beginning, the requirements of the farms were queried to the AFS in order not to falsify the answers with already asked detailed questions. Based on the distribution in Figure 1, it can be stated that, above all, the "reliability of the system" has "absolute priority" among the persons surveyed or is "very important". As well as very important characteristic was mentioned above all the "security for humans and animals" as well as the "time saving". Less important were "technical progress" and "modernization of the business". The factors "animal control" and "quality control of feed" are also important for the persons interviewed. The importance of low acquisition or low maintenance costs is in the midfield.

The reliability of the system is an important point. This concerns in particular the failure safety of the plant, since, depending on the system, the building structure is restructured in such a way that it can no longer be fed with a standard system. The feeding can then be done only by hand which is a significant peak work in the number of animals. Also important in this context is the proximity to customer service. This is the most important aspect of choosing between different manufacturers in most farms. In this group of questions there were also often reported experiences of old AFS from the 1960s, even if the farmer has not personally experienced this.

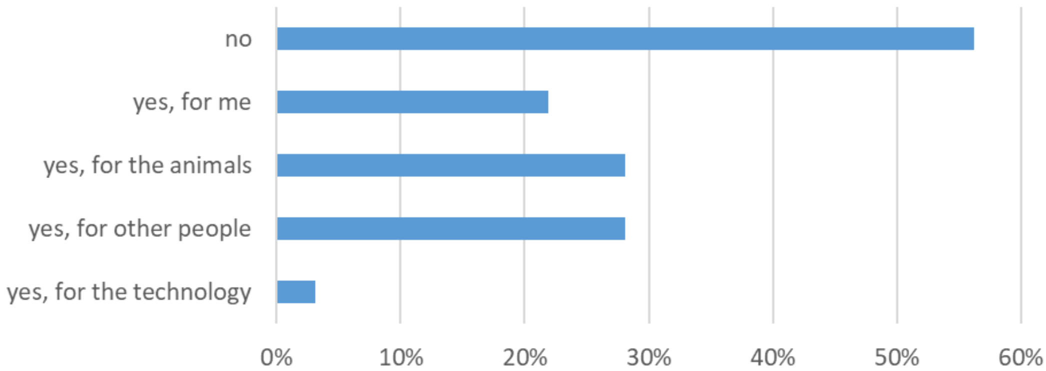

Figure 2. Security concerns for automatic feeding systems

Also, with a very high priority the security for humans and animal was mentioned (Figure 2). In comparison, 56 % of respondents see no direct danger despite this high priority across all farms. The main concern of the respondents is the safety of animals and third persons (28 % each), especially in fully autonomous systems with their own feed intake in the silo.

In feed quality, 58 % tend to direct silo removal without intermediate storage to prevent feed spoilage. Short-term temporary storage of up to one day would still be acceptable for 39 %.

The responses about the control options of the AFS are evenly distributed over all possible answers, only the control via a remote control was considered sensible by only 27 %. The most popular is the control of an app for the smartphone (63 %).

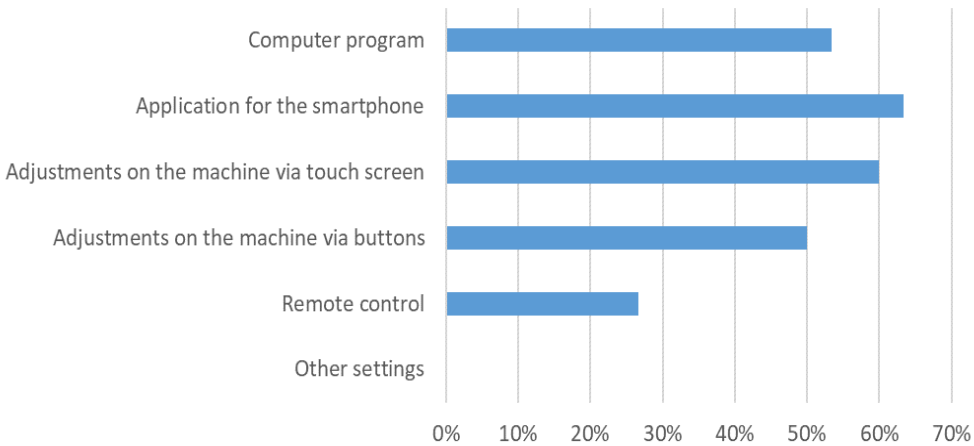

Figure 3. Control system for automatic feeding systems

The targeted energy supply of the system also reveals the trend towards electrical drives in agriculture. A previous study revealed that 52 % would prefer to drive on batteries, 27 % would prefer a separate track and only 21 % would choose a combustion engine (Oberschätzl-Kopp, 2018). In this picture also fits the 45 % of respondents' self-generated electricity for operation use.

Clearly answered was the question whether the AFS was manually generated, e.g. should be used in old buildings. This was answered by 100 % of the farms with yes.

As the analysis of willingness to pay illustrates, there is a clear tendency that respondents are willing to spend more, depending on the level of automation. While a simple feed pusher is only worth a maximum of € 10,000 (71 %) for most participants, they are willing to spend up to € 50,000 (84 %) on the current standard (attached, externally loaded mixing wagon). For a semi-automatic system, the respondents say costs of € 75,000 are reasonable (90 %), while a fully automated system may cost up to € 100,000 (80 %). Only 5 people (16 %) were willing to invest up to 150,000 € for the fully automatic variant.

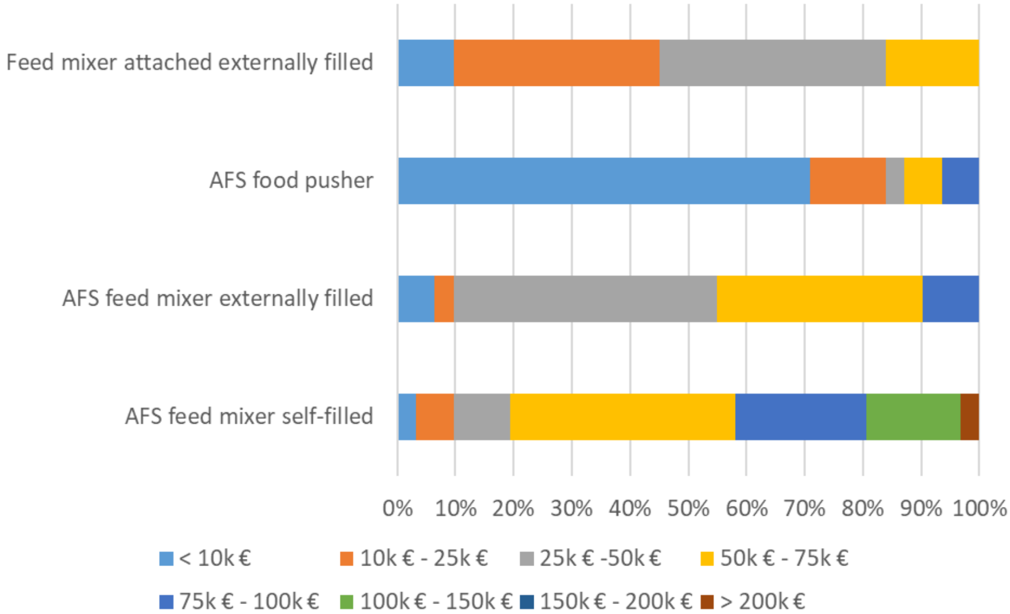

Figure 4. Cost estimate for an automatic feeding system

4. Discussion

The evaluation of the questionnaire revealed some clear preferences. So it was considered by all participants to be useful to be able to use an AFS manually even in old buildings. The most important for the respondents was the reliability of an AFS. In addition, the high feed quality must be ensured by the correct storage of the feed, even outside the silos. Another advantage for the participants was the combination of mixing and transport wagon, i.e. a departure from the stationary mixer. The energy supply with batteries was the most preferred.

Some of the respondents' concerns could also be categorized. Doubts about security are rather subliminal, while the technical reliability of the AFS is in the foreground. Looking back at the interviews that led to the development of the questionnaire, connections could be established. The Farmers subgroup has already expressed concerns about a possible machine failure, as well as a possible lack of service by the manufacturers.

It was interesting that the majority of the participants were prepared to invest a higher sum in the acquisition of an AFS, if this can then be operated more cost-effectively and effectively saves working time.

5. Conclusions

It is noticeable in the investigation that, despite many young respondents, a certain scepticism can be observed. This is probably explained by the lack of knowledge about automated systems. Currently, it seems that the worries about safety dominate the debate about these automatic feeding systems rather than its many advantages. The industry needs to pick up this discussion and convince potential users about their safety issues with good communications, practical testing and relatable advertising.

Working hours play a crucial role for AFS as feeding after milking is the second major work block in classic operation. Therefore, it is assumed that especially companies with AMS will be interested in AFS in the future. This aspect was also experienced in the survey. However, it is to be observed that the possible change cause uncertainties in the field of animal control. This is currently involved in feeding and would then have to be reorganized. The shifts from physical work in feeding to more mental work in animal management is difficult to estimate by respondents. Sometimes it is even mentioned if this does not make even more work than now. This indicates the complexity and abstractness of automation and digital processes farmers are faced with. Companies need a clear vision and understanding of their products to simplify and increase usability for farmers.

Also important for farms is the flexible use in old buildings or with a manual driver, which speaks against rail-bound systems. For fully autonomous systems that bring the feed itself in the silo speaks the desire for high forage quality without intermediate storage. Farmers know the impact of not only varying components in ratios but also its nutrition quality. It has to be goal to automate routine work that is also not very crucial. Work that is very critical for the processes on farm need to be supervise easily by the farmer. The expansion of renewable energies and the trend towards sustainability and autarchy are reflected in the result, that Electric drive systems are preferred by most farmers. It can be expected that more farm machines will be available with electric drive in near future.

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LARGE-SCALE POINT-CLOUD BASED GLOBAL MAPPING FOR ORCHARD OPERATIONS

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ABSTRACT

Robotic motion in orchard fields consists of several components such as mapping, perception, navigation, and route (path-motion) planning. Route planning and navigation are highly contingent on mapping functionality whilst the robotic vehicle operates and adapts itself into a partially known work area providing a safe and accurate routing. Traditional mapping techniques entail an unmanned ground vehicle equipped with laser scan sensors and inertial measurement units resulting to a spatial 3-dimension map, which is a comprehensive guide for the robotic vehicle. The proposed system here takes advantage of the complementary mapping operation of an unmanned aerial vehicle's ample flight height for enhancing its mapping ability. This approach can provide a ground-breaking perception solution especially in agricultural fields, where the targeted area covers extremely wide-open spaces. This combined mapping process reduces the time needed by a ground vehicle for mapping the environment by itself, while it reduces the risk of accidents and operational failures. Furthermore, the ability to implement a camera and a GPS sensor on the vehicle, enables the tree indexing resulting to a significantly more accurate ground vehicle navigation. Additionally, the trees are associated with their geolocation providing future applications with valuable information. The digital map documentation is compliant with a seamless integration with the precision agriculture framework, enhancing field mapping value.

Keywords*:* precision, farming, robotics, UAV, UGV, mapping

1. INTRODUCTION

Mapping is one of the most important fields in robotics, and it is an inseparable piece of the robotic motion and navigation (Bochtis et al., 2007; Hameed et al., 2013). Regardless of the vehicle type, unmanned ground vehicle (UGV) or unmanned aerial vehicle (UAV), mapping is the field in which the robotic vehicle obtains the perception of the area that exists. Combining the sensor data from several sensors like GPS, inertial measurement units (IMUs) and laser range finders (LRFs), the robotic vehicle can estimate its position, localization and velocity. Hsu et al. (2018) proposed an algorithm that combines the advantages of simultaneous localization and mapping (SLAM) using an RGB-D camera and the IMU/laser SLAM.A Microsoft Kinect, a Hokuyo laser scan and an IMU were fused in order to produce the 3D positioning and mapping results. The extended Kalman filter is used for drift correction from the inertial sensor, which is estimated from the Kinect sensor. When the displacement estimated from Kinect sensor is marked as a failure, the vehicle's velocity is estimated from the laser scan. A remarkable research is done by Torres-Sánchez et al. (2018) where he combined the photogrammetric point clouds with an object-based image analysis (OBIA). The research took place on three different almond orchards using a UAV equipped with a visible-RGB sensor while the validation field method consisted of registering the height of a total of 325 trees in two fields. The OBIA algorithm had the high

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score of $R^2 = 0.94$ while it was used for generating 3D maps for every tree volume and volume growth which would be useful to understand the relations between tree and crop management operations in the context of precision agriculture. An unsupervised detection of vineyards by 3D point-cloud UAV photogrammetry was proposed by Comba et al. (2018) using a UAV. The initial data was created by a multispectral camera which was equipped on the UAV, while the produced 3D point-cloud map was parsed by the proposed innovative unsupervised algorithm. The main results are the automatic vineyard detection while the local evaluation of vine rows orientation is calculated. A research about monitoring 3D areal displacements using a UAV was done by Hastaoğlu et al. (2019) proposing a UAV benchmarking approach. Using a UAV, equipped with GNSS receiver, they produced orthomosaics and digital elevation models (DEM). Based on the coordinates obtained, the velocity values where calculated by the Kalman filtering technique. The velocity values were considered as equal was determined by statistical analyses techniques like t-test, f-test, RMSE and VAF. A really interesting approach was made by Wu et al. (2019) proposing a 2D-to-3D strategy for invasive plants in a mountain area. Invasive plants institute one of the major causes for biodiversity loss. The study took place over mountain region in Shenzhen, China deriving multi view images from an UAV, using a high precision 3D mesh-model and digital orthophoto map. A fine analysis was introduced in order to produce the 3D dimensional distribution by combining the 2D distribution with the 3D respective mesh model. Sünderhauf et al. (2016) suggested an object-oriented semantic mapping using an RGB-D camera sensor. Despite the traditional process of 3D mapping, Sünderhauf implemented an image-based deep-learning object detection and 3D unsupervised segmentation aiming to allow the intelligent robots understand both geometric and semantic properties of the scene surrounding them. Remaining on the semantic mapping approaches, McCormac et al. (2016) introduced an approach that consists of the combination of Convolutional Neural Networks (CNN) and a SLAM system named ElasticFusion. ElasticFusion provides long-term dense correspondences between frames of indoor RGB-D video. Using the CNN, the study targets to predict the multiple view points and be fused into a map. The remarkable point on this apporach is the matter that the frame-rates are approximately 25Hz, providing a real-time interaction. On the terms of localization and mapping, Salas-Moreno et al. (2013) presents the advantages of a new kind of SLAM which involves objects. Despite the traditional SLAM which operates at the level of low-level primitives such as points,line and patches, the object oriented SLAM harnesses 3D object recognition in order to jump over the low level geometry and create an implementation of object detection and six degree of freedom. Additionally, Bosse and Zlot (2009) introduced an algorithmic approach which is based on the well-established Iterative Closest Point (ICP) scan matching algorithm. This approach was executed using a 2D laser scan sensor for 3D mapping. Cole and Newman (2006) equips a UGV with a laser scan in order to produce a point cloud data, used for mapping and navigation of the vehicle. Despite the traditional SLAM techniques, Cole and Newman, supervisingly trained a classifier in order to reject poor scan-matches from the map scanning process. Last but not least, Bosse and Zlot (2008) challenged with the fact that the sensor motion is fast relative to the measurement time is that scans become locally distorted and difficult to align. The proposed solution consists of a 3D scan-matching combing with a continuous 6 degrees of freedom sensor trajectory which is recovered to correct the point cloud alignments. As a result, the product encompasses accurate maps and high vehicle motion reliability.

In this paper, a 3D mapping approach is presented. The process contains a UAV photogrammetry technique using an RGB camera, a laser sensor and a Real Time Kinematic (RTK) GPS receiver in order to obtain the data from the field. After that, the process is being processed via a proprietary software while the point-cloud of the field is constructed. Although, the produced point-cloud is not reliable enough in order to be a working mapping base for the UGV. Consequently, a preprocess action took place in order to create a solid mesh model using a triangulation technique. In the end, the mesh model was transformed to a map file which is recognizable from the UGV. Since this step was successed the navigation of the robot was a straightforward process.

2. IMPLEMENTATION

A mapping process requires both software and hardware integration, both consisted in a vehicle. The hardware implementation contains the necessary sensors and materials while the software implementation contains the external software used for data manipulation and product result. Vehicle's software is also considered as hardware implementation and it will be detailed below.

2.1 Hardware integration

This subsection briefly describes each hardware component used in the mapping approach while the need of environment recognition is tightly connected with the sensors. The fixed-wing drone constitutes the main core of the mapping process. Possessing a high flight time duration, senseFly's eBee is able to imprint large scale areas in order to produce orthomosaics and point-clouds. It is equipped with an RGB camera called SODA which is a proprietary RGB camera for the eBee and it is connected via the integrated USB port. The drone is also equipped with an RTK GPS in order to optimize the aerial navigation and precision while a vertically mounted laser scan is constantly measuring the flight height of the drone. Despite the aerial vehicle, the described approach contains a laptop computer, which is responsible for drone's control and command. The antenna of eBee's controller is communicating with the proprietary USB antenna which is connected to the laptop. This ground station contains the necessary software, aiming to provide the most reliable result regarding the drone and the computer communication (Figure 1).

Figure 1. SenseFly's eBee, the RGB camera and the antenna

2.2 Software implementation

Software constitutes the core of the drone and the process itself. The embed proprietary eBee software is reliably connected with the software running to the ground station while providing any real time useful information about the UAV. The proprietary software, eMotion, comes packed with all necessary drivers and communication protocols in order to achieve a successful connection with the aerial vehicle. On the other hand, the final product of 3D mapping is being produced by the Pix4DMapper Pro software while it manipulates the recorded data from eBee.

2.3 Process

The proposed process consists of multi-level subprocesses since the final product is complicated to be produced. From ground station preparation to UGV navigation, the mapping process of a large-scale area is structured by different type of implementations while the whole process is a sequentially executed series of actions (Figure 2).

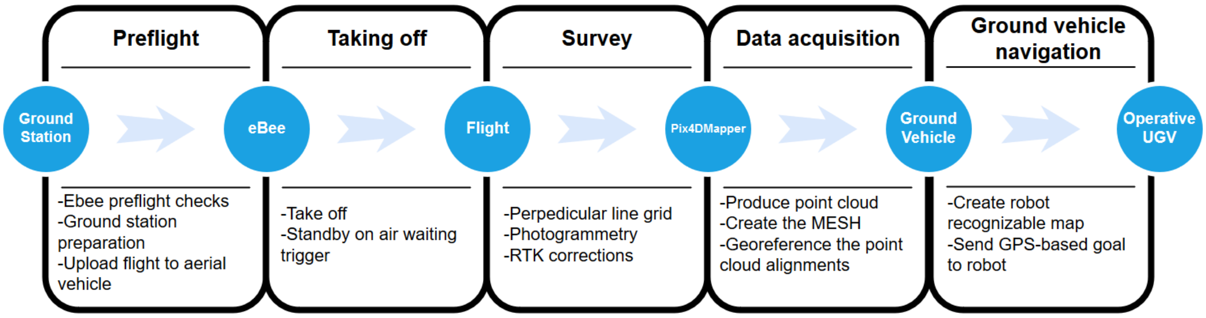

Figure 2. Required actions until mapping result

Once the mapping procedure is completed, the result is being edited and imported to a ground vehicle in order to benchmark the integrity of produced map.

3. Results

The mapping process provides a collection of georeferenced images of the field, where the Pix4DMapper Pro software is responsible for point-cloud construction. Since the produced point cloud is not reliable enough to be imported to the ground vehicle, a mesh model was created using a triangulation method applied on the point cloud file in order to cover up the hardly accessible spots that drone missed due to canopy size (Figure *3*).

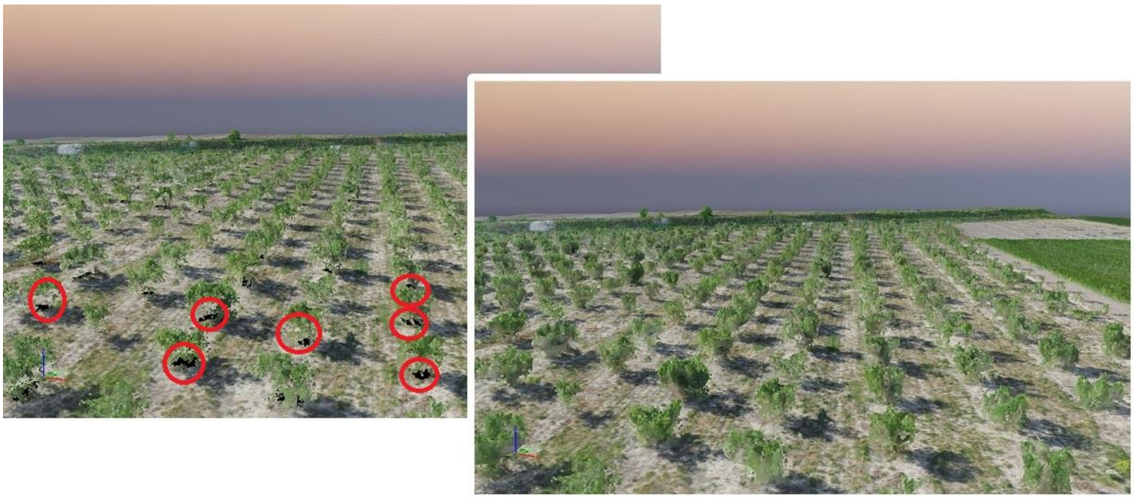

Figure 3. From point-cloud to mesh model

Covering up the spots allows the robotic software to create a robot-friendly map. The ground vehicle that was used is operating based on the ROS framework (Quigley et al., 2009) (Figure 4) which

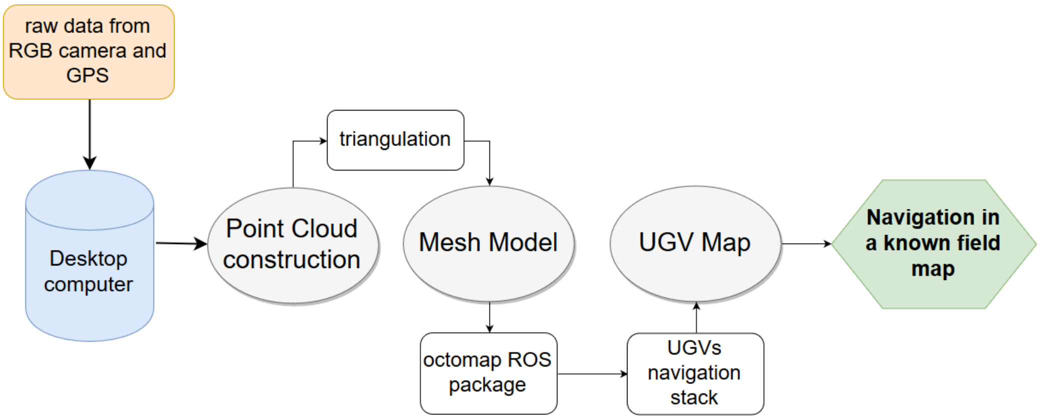

Figure 4. From raw data to useful product

combines both the core and the visualization software for the robotic operations (Figure 5), providing a complete solution on robotics navigation and manipulation. From the ROS framework side, the octomap package was used in order to convert the mesh model to a UGV map.

Figure 5. Benchmarking the mapping product with real robot

The benchmarking result was satisfying while the robotic vehicle was navigated safely among the orchard trees, reaching the desired goal that users targeted with the assistant of the robot's algorithmic planner. Despite the fact that some expected errors existed such as inaccuracy of mapping product GPS coordinates and actual coordinates measured by the vehicle's GPS, the approach is nearly matched with the desired result.

4. Future work and conclusion

In this paper, a large-scale point-cloud based mapping using an unmanned aerial vehicle was presented. Aerial vehicles are commonly used in precision agriculture exploiting their ability of high observation of a large area and their energy cost awareness. Fetching the data from the UAV, manipulating the resources and importing the product into a real robotic vehicle, the mapping process is completed in a reduced duration, comparing with the mapping time that would cost to a UGV on the same field area. The bleeding edge feature of this work, consists of high-speed mapping process with an aerial vehicle, avoiding using the traditional time consuming UGV mapping.

The proposed process can be used by many applications such as virtual interactions and robot navigation. In the future, the interest is focused on the GPS matching improvement, a real-time mesh model and map creation while the cooperation of UGV and UAV on mapping, is marked as the main goal.

Acknowledgements

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ASSESSING FEASIBILITY OF SOYBEAN SUBSTITUTION WITH ALTERNATIVE LEGUMINOUS CROPS FOR SOUTH EAST EUROPEAN COUNTRIES

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ABSTRACT

It is a fact that there is a high trade deficit (around 70%) in Europe with regards to protein crops. This is a significant reason for the EU to implement policies aiming at reducing the dependence of imported materials with high protein content for animal feed use. Due to their competitive prices, soybeans imports from the USA and China are particularly attractive choices for European importers and feed users. A very promising policy approach to tackle this phenomenon seems to be the implementation of production protocols for the legumes cultivation, based on the sustainability and use of economically and environmentally friendly practices in accordance with European directives. Following this line of reasoning and taking into account all the existing constraints in Southern Europe for achieving sustainability, this work explores a time period 2007-2016 evaluating four main high protein crops so as to evaluate the feasibility of a successful soybean substitution. *Pisum sativum subsp. arvense L*. and *Lupinus albus* are -the species primarily examined in this research, in an attempt to replace partially or completely the soybean meal in the dairy cow diet. In addition, this research evaluates the impact of these legumes on the environment through crop rotation, which has significant implications for environmental indicators improvement. Considering the actions presented in the second pillar of the EU Common Agricultural Policy, an attempt is made to replace the imported soybeans while preserving national natural resources. EU policy should support the cultivation of such local high protein crops in order to achieve Sustainable Development Goals.

Keywords*:* livestock feed, soybeans, legumes, Pisum sativum, Lupinus albus, South Europe

1. INTRODUCTION

From 2012 to 2019, soybean production has been raised from 250 to 350 million tones with USA, Brazil and Argentina holding the leading positions, producing almost 75% of overall production (USDA, 2019). On the other hand, China and European Union are the primary importers of soy, using soybeans and soymeal mainly as feed. Dominance of soybeans in animal industry has been established due to its high protein concentration over its volume. European Union is highly dependent in USA soybeans imports, so as to cover animal nutritional needs.

Aiming to reduce economic and environmental cost of imported amounts of soybeans, EU seek ways, through new CAP after 2020, to boost protein crop cultivation. It has been stated that European soybeans production can cover only 5% of total needs of soybean in Europe (European Commission, 2018). Combining the above mentioned with the fact that EU has one of the largest meat consumption per capita, alternative solutions should be implemented. Alternative leguminous crops can be a

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feasible solution, in order to achieve continental sustainability under climate change index, where minimum resources should outcome qualitative products that meet quantity needs.

Alternative leguminous crops present appropriate characteristics for animal industry use, in order to substitute soybeans crop which has high needs of chemical inputs, resulting in environmental damage (FAO, 2009). There is a growing interest in use of legume- based green manure stemming mainly from the rising cost of synthetic inputs and concerns about the environmental performance of agriculture. For this reason, high protein crops can be used as a part of a crop rotation resulting in improved soil properties, and nitrogen supply for the following crop. It has been shown that this type of manure can increase soil nitrogen availability, as atmospheric nitrogen is absorbed by the legumes, and subsequently incorporated into manure by nitrogen assimilation (Baddeley, 2017). Using minimum amount of fertilizers leads to great decrease of greenhouse gases, due to the high needs of energy for their manufacture. Additionally, local legumes production contributes to GHG emissions decrease due to minimum need for transportation in comparison with the imported quantities. Another crucial point, is that less water is needed during grain filling, a significant characteristic for areas that are facing elongated periods of drought.

Literature review of Palhares & Pezzopane (2015) concludes that leguminous crops can be an alternative source of feed for the European Union countries, underlying the significance of support measures and appropriate plant breeding programs. Main restrictions for adaptation of alternative leguminous crops are that 1) they present lower levels of proteins in comparison with soybeans 2) their cultivation is not very common and for this reason farmers are afraid to adopt a newly introduced crop, 3) there are not enough quantities to cover EU animal industry needs and permit their further expansion. Leguminous crops not only do not affect the quality and the quantity of milk production, but also increase animal welfare by decreasing urea levels in their blood (Tufarreli et al., 2012)

In the light of these observations, this document highlights the market situation and market dynamics of Southern European countries in the production of high protein vegetable sources for animal feed. At the outset, the development of the production of the main protein crops is outlined, including mainly soybean, lupine, green beans and green peas cultivation. Furthermore, data such as annual production volumes, yield and value added for each of these crops are recorded and analyzed. Secondly, country-level data are analyzed to better outline European soybean and other legumes production. Through this document, an attempt to outline the mix of protein crops grown in South Europe is made, while at the same time we highlight the most efficient crop in terms of land use and production value. This paper seeks to address the following research questions:

- Are there any changes regarding soybean production for the last decade in SE European countries?
- Does soybean production present high efficiency level in land use and economic profit index?

2. METHODOLOGY

Data has been collected from Food and Agriculture Organisation (FAO) and Eurostat referring to the 2007-2016 period in order to investigate alterations of protein crop mix in South-European countries. Four main leguminous crops have been selected for this paper due to their high protein concentration, environmental and economic significance. The countries taken under consideration are presented in Table 1. Analysis is conducted by utilising basic statistical measures as well as correlation analysis, as appropriate.

Table 1. Description of the key data of the paper

Crops	Total Output (tonnes)	Yield (Hg/ha)	Total Value	CO_2 and N_2O direct emissions
Green beans	X	X	X	
Green peas	X	X	X	
Lupinus	X	X	X	

Soybeans	X	X	X	X
Countries	Albania, Bosnia, Bulgaria, Croatia, Cyprus, France, Greece, Italy, Malta, Montenegro, North Macedonia, Portugal, Romania, Serbia, Slovenia, Spain			
Years	2007-2016			

3. RESULTS

3.1 Investigating the mix of high protein crops in South-East Europe

Annual production of selected crops from South-East Europe countries is depicted in the following figure (Figure 1). It can be easily seen that protein crop production has almost been doubled within the last 10 years. Although, production of high protein crops has not been increased accordingly. Green peas and lupins have remained stable during the whole reference period 2007-2016, while there is a slight decrease of green beans. Soybeans production remains at same levels between 2007-2009, a temporary increase for the next year and then decreasing in the initial levels of 2009. However, 2012 seems to be a very crucial year from which, EU soybeans production has been increased 2.5 times.

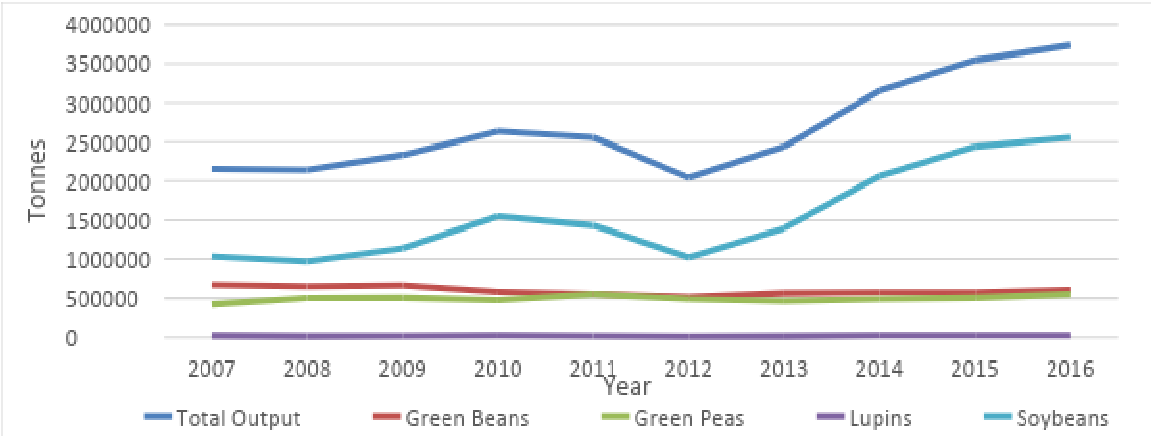


Figure 1. High protein crops production is SE Europe (2007-2016), Source: FAO, 2019

After 2012 there is an apparent dominance of soybean over the other leguminous crops, resulting in a completely different protein crop proportion mix. From 2007 to 2016, green beans ratio has been shrunk from 31.3% to 16.2% accordingly (Figure 2). A smaller decrease is being depicted for green peas and lupines for the same years. However, soybean output has been increased from 48% to 68.4%, meaning that there is a remarkable shift to soybean production from SE Europe countries.

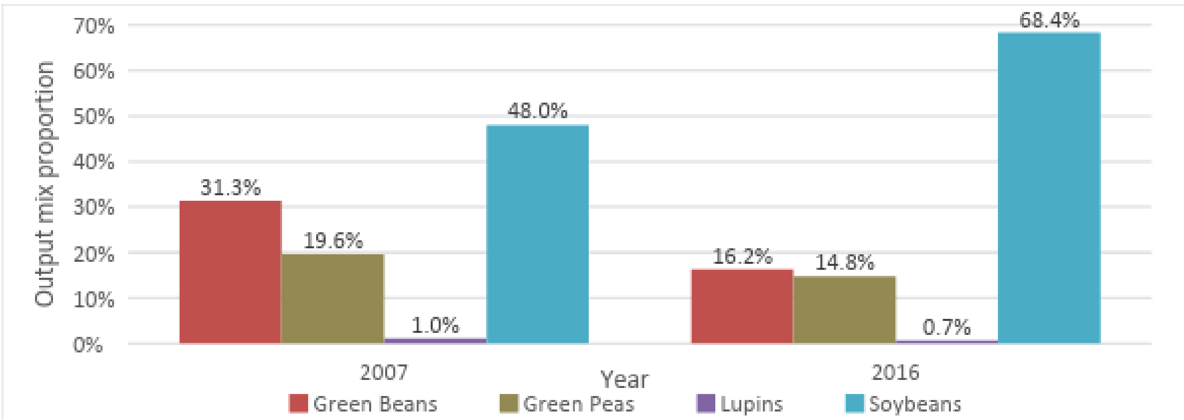
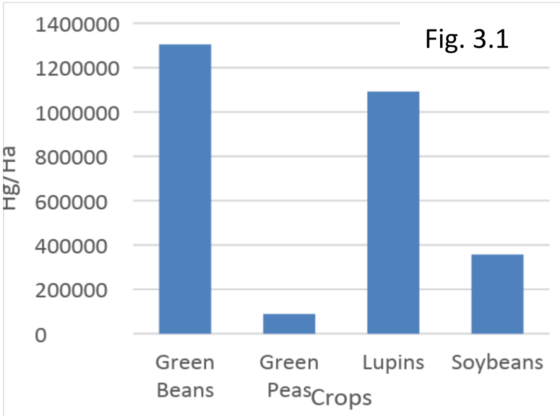


Figure 2. Proportion of the four high protein crops in the total output mix of SE Europe (2007-2016), Source: FAO, 2019; Authors elaboration

3.2 Investigating the yield and value of the high protein crops

In the following figure the average yield (hg/ha) and the value (International $/Kg) of the four high protein crops are presented for the countries of SE Europe (Figure 3). Green beans appear with the highest productivity level among the four leguminous crops, scoring around 1.3 million hectograms per hectare, followed by lupines producing about 1.1 million hectograms per hectare. Soybeans present 65% less yield than lupines, while green peas production levels remain very low at about 100 thousand hg/ha. Assessing the economic values of protein crops per kilo, it is being revealed that green beans return about 0.33$/kg. Green peas are the second ones, with an average price of 0.31$/kg followed by soybeans with 0.28$/kg. Lupines have the lowest price of 0.16$/kg. From the above mentioned results, it seems that excessive soybean production has led SE European countries to loose both in productivity and income, whilst they could have focused in specialization of green beans production.



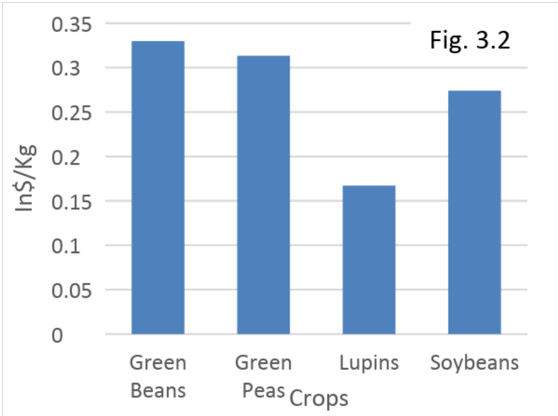


Figure 3. Yield (Fig. 3.1) and value (Fig. 3.2) of the four high protein crops in SE Europe (2016), Source: FAO 2019; Authors elaboration

3.3 Investigating the individual records of countries in soybean production and its relationship with the performance of the agricultural sector

Table 2 gives an insight of soybean production in SE European. More precisely, production, proportion of soybean in crop mix, yield and changes in soybeans in the period 2006-2017 are presented. Italy, Serbia and France have achieved the highest production while on the other hand highest dependence in soybean production is depicted from Croatia, Bosnia and Serbia. In the timeline of 2006-2017 only Albania has a reducing rate of soybean production. Greece, Bulgaria and Slovenia present the highest increase. Greatest yields have been achieved by Italy, Croatia and Spain. Considering the environmental impact of soybean production, CO_2 and N_2O per product have been assessed. Greece and Spain were able to produce soybeans with the least of emitted amount of greenhouse gases.

Table 2. Basic figures of soybeans production in the countries of SE Europe, Source: FAO, 2019; Eurostat, 2019; Authors elaboration

	Soybean Production (tonnes)	Soybean Proportion	Soybean Change	Soybean Yield (HG/HA)	CO_2/Product	N_2O/Product
Italy	1,081,340	80%	37%	37,539	0.0577	0.0019
Serbia	576,446	89%	11%	31,610	0.0605	0.0020
France	338,864	52%	99%	24,849	0.0655	0.0021
Romania	263,380	80%	16%	21,045	0.0697	0.0022
Croatia	244,075	97%	8%	31,047	0.0609	0.0020
Bosnia	18,662	90%	11%	26,576	0.0640	0.0021
Bulgaria	18,301	60%	6870%	12,923	0.0869	0.0028

Slovenia	7,387	68%	474%	29,955	0.0615	0.0020
Greece	4,000	5%	31417%	25,806	0.0567	0.0018
Spain	2,869	1%	208%	28,830	0.0452	0.0014
Albania	664	4%	-11%	25,152	0.0652	0.0015

Table 2 illustrates the significant differences between countries' efficiency in soybeans cultivation. It seems, therefore, that countries which do not have the capacity to make effective use of their natural resources are forced to cultivate exclusively soybeans and thus suffer from a lack of competitiveness. This led to the need to conduct a series of correlational analyses to assess the relationship between soybean production and the efficiency of the country's agricultural sectors (Table 3). This analysis correlates the level of country specification in soybean production with four different variables that represent different dimensions of efficiency related to soybean production and the agricultural sector in general. The first variable is defined as the total yield of cultivated protein crops and the results show that soybean specialization is capable of leading to loss of yield, as there is an inversely proportional relationship between soybean specialty and high protein crop efficiency. The second variable depicts the output value per unit of output and, as in the first variable, the relationship to soybean specificity is inverted, a fact that is shown by the negative and statistically significant correlation coefficient. From this variable, it appears that countries that specialize in soybeans show a decline in generated value. The third variable, this of CO_2 emission per soybean production unit, is not statistically significant, a fact which proves that the increase in soybean specialization does not have a positive impact on the environmental efficiency of the crop. The fourth variable, expressing soybean yield, is not statistically significant too and therefore the conclusion is that there is no linear relationship between soybean specification and soybean yield.

Table 3. Results of the correlation analysis among the level of specialisation and effectiveness of agricultural sectors in SE Europe

Variable	Total yield	Generated value	CO2 Emissions	Soybeans yield
Spearman Coefficient	-0.502*	-0.849***	-0.125	0.404

*** Statistical significance (two-tailed) at the 0.01 level.
** Statistical significance (two-tailed) at the 0.05 level
* Statistical significance (two-tailed) at the 0.10 level

4. CONCLUSIONS

In this paper, evolution of high protein crops during the period 2007-2016, in South East Europe is depicted. An overall increased protein production is obvious, resulting in less dependence of soybean imports. Moreover, soybeans production has been increased 2.5 times from 2012-2016, meaning that soybean is a main importance high protein crop for SE Europe countries. On the other hand, this research reveals that higher yield and prices can be achieved from green beans. Combining this with the above-mentioned increase of soybeans, it can be stated that green beans should earn a largest proportion of high protein mix, minimizing soybean imports and increasing net values. In the second part of this paper, specialization in soybean production, seems that it does not affect production and yield, whist there are no significant differences in the overall efficiency.

Taking all the above mentioned into consideration, significant differences are observed between the EU strategy for high protein crops cultivation and final outcomes. Although EU states that soybeans imports should be minimized by focusing on alternative leguminous crops for increasing self-sufficiency and environmental protection, data shows a clear dominance of soybeans in SE Europe. For many years, EU has implemented a series of tools in order to promote production of certain crops, covering people needs at the time given. It still remains a goal for the EU to support alternative leguminous crops under the upcoming CAP (2020-2024), in order to achieve Sustainable Development Goals.

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Investigating Ways to Develop and Control a Multi Purpose and Low Cost Agricultural Robotic Vehicle, in Scale

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Abstract

Agriculture is a sector that is rapidly changing due to the technological advances of our era, but is not always easy for the students to catch up with this fast evolving process. A good way to tackle it is to let them experiment trying to develop innovative robotic vehicles for agricultural purposes. This paper describes exactly the trials being made to design and implement an electric robotic vehicle, in scale, in a cost-effective manner, using metal, wood, recyclable materials and small motors. Students experimented with bipolar stepper motors as well as with brushed DC motors and performed a comparative study between the two types. Starting from configurations involving only one Arduino Uno board, students shifted to scenarios with more components, and even with Raspberry Pi units, in order to better understand fundamental automatic control principles and remote operation issues. The trials made to properly program the robot using both visual and textual programming environments are also reported. Most of the remote interaction scenarios have been carried out through Wi-Fi interfaces, while some of them involved LoRa interfaces to extend the effective controlling distance of the robot. For better efficiency and autonomy, a small solar panel unit has been adapted on the top of the robot and energy consumption for different configurations has been studied as well. Finally, the paper, going beyond strictly educational purposes, reports on characteristic derived robotic layouts and proposes possible "real-world" use case scenarios.

Keywords*:* Agricultural Vehicles, Smart Control, Energy Consumption, Educational Robotics, Project Based Learning

1. Introduction

Agriculture is, beyond any doubt, one of the most important sectors of primary industry, yet it is characterized as sensitive, unstable, complex, dynamic, and highly competitive. In the twenty-first century, according to FAO, agricultural productivity should be increased by 60% in order to ensure a safe food supply which would adequately satisfy the nutritional needs of the constantly growing world population (FAO, 2013). This goal has to be achieved despite the fact that the required resources are already stretched, as the amount of available agricultural land is declining due to increasing urbanization, soil erosion, and high salinity levels, while 70% of the world's freshwater supplies are consumed for agricultural purposes. In addition, it is required for agriculture to address the issues which arise from the global climate change, concerning the reduction of its greenhouse gas emissions, as well as the adjustment to extreme weather conditions which impact the quantity and

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quality of the crops (FAO, 2013). To successfully tackle these issues, the sector of agriculture has to become more productive and "climate-smart", by successfully exploiting a variety of existing and emerging technologies (Symeonaki et al, 2019). Among them, Robotics and Autonomous Systems (RAS) technologies could positively contribute to the transformation of the agri-food sector (Bechar and Vigneault, 2016; Bechar and Vigneault, 2017; Krishna, 2016; UK-RAS Network, 2018).

Robotic platforms equipped with a variety of remote and proximity sensors and making use of low cost Internet of Things technologies, advanced analytics, computational intelligence tools, machine learning techniques, advanced automatic control schemes, future telecommunications and Cloud computing technologies could provide information about soil, seeds, livestock, crops, costs, farm equipment and the use of water and fertilizer. It is expected to make more intelligent decisions about the level of resources needed and determine when and where to distribute those resources in order to minimize waste and maximize yields, in the context of Precision Agriculture.

The involvement of robotic automation in the field of Agriculture would also help to attract skilled workers and graduates to the sector. Therefore, it is very important to educate future agricultural engineers in the disciplines and technologies that are involved in modern robotics but is not always easy for students to catch up with this fast evolving process. A good way to tackle such difficulties is to let students experiment trying to design and to implement (i.e., to construct and program) similar robotic vehicles on their own, assisted by innovative systems that have recently made the scene and are becoming very popular among the student communities willing to develop similar projects, without the barriers that strictly commercial educational robotic solutions are posing (Doran and Clark, 2018).

This paper describes exactly the trials being made to develop an electric robotic vehicle, in scale, in a cost effective manner, using metal, wood, recyclable materials and small motors. The students experimented with bipolar stepper motors as well as with brushed DC motors and also performed a comparative study between the two types. Starting from configurations involving only one Arduino Uno (Arduino, 2019) board, the students shifted to scenarios with more Arduinos and even with Raspberry Pi (Raspberry, 2019) units to be familiar with fundamental automatic control functions (in terms of speed and direction stabilization) and remote operation issues. The paper also reports on the efforts made to properly program the robot using both visual and textual programming environments. Finally, the paper presents typical use case scenarios and highlights open issues and plans for the future.

2. REQUIREMENTS AND DESIGN OVERVIEW

The specific goal being set for the students of the specialty of Farm Machinery, at the Agricultural University of Athens, was to design, implement and test a DIY robotic vehicle, in scale, that could host various sensors for environmental measurements or perform light farming activities, like planting seeds, spraying or carrying light crop cargos. This robotic vehicle had to be simple to manufacture, durable and cost-effective. Furthermore, it should have a moderate size and torque, more than one hour autonomy and the speed of a walking man, without being too heavy or too greedy, in terms of energy consumption. Finally, the vehicle should be able to roll on slightly anomalous or inclined terrains. The basic robotic vehicle design principles are depicted in the left part of Fig. 1.

As this robotic vehicle was intended to serve as a "vanilla" platform for testing environmental sensing equipment or to perform light duty agricultural tasks, a mechanism for commanding it, either locally or remotely, should be incorporated as well. For this reason, the low level controlling tasks had to be addressed locally by an Arduino Uno unit, installed on the robot and accompanied by simple electronic components like potentiometers and suitable motor-driving equipment. For the high level tasks, like providing remote human-robot interaction, the robot had to be equipped with a Raspberry Pi unit able to run python (or C) code and to act as a bridge between the fixed on the robot Arduino and the smart phone of the user. The latter device should provide commands via its touch screen, its accelerometer sensor or via a cloud-based voice recognition mechanism, in a way based on and extending the methods described in (Loukatos et al, 2018). In recapitulating, both visual (e.g. Ardublock and MIT App Inventor) and textual (e.g. Arduino IDE, C, python) programming environments were used to provide a satisfactory behavior for the robotic vehicle.

3. Implementation Details

The selection of the hardware components intended to minimize the size and the cost and maximize the reusability. Software design and implementation was following the same principles.

Taking the abovementioned requirements under consideration, students resulted in a layout involving two independent electric motors giving motion to the wheels of each side, through a chain drive system. This setup eliminates the need for extra mechanisms dedicated in steering tasks, provides simplicity, robustness and increased maneuverability. The basic robotic vehicle layout using two stepper motors is depicted in the right part of Fig. 1.

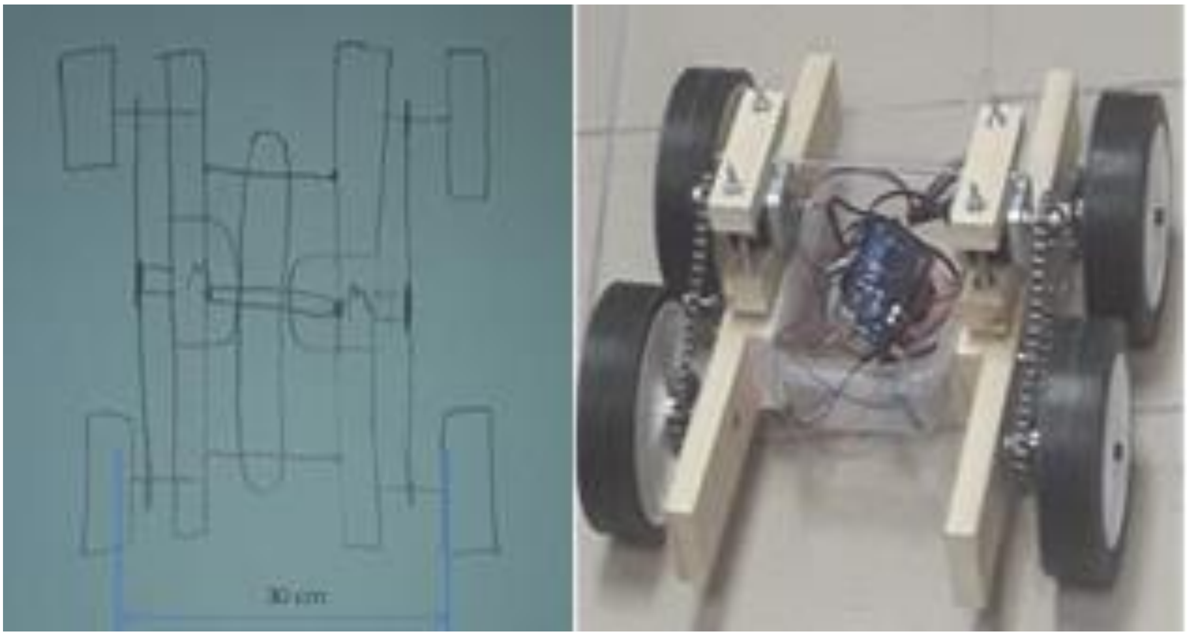

Figure 1. Initial robotic vehicle design providing one independent motor per-side and all-wheel drive (left). An early implementation using stepper motors (right)

Indeed, it is mainly a two separate parts (i.e., left and right) design, parts that are connected via threaded rods, of 3mm in diameter, thus providing suspension elasticity. The control of the motors was to be done by a microcontroller (Arduino Uno), via suitable power electronics (motor drivers mainly of L298 type). The necessary power would be provided by power banks or deep discharge batteries. Size specifications tend to a 40x40 cm layout. The motors to be used should deliver a torque of around 5kg-cm, at 100 rpm, in order to have a combined drag force of around 4kg, taking into account the revolution reducer (:3) and the given wheel diameter (approximately 7cm).

According to the Initial requirements for locally controlling and testing the robot two potentiometers were fixed on the robot, for selecting the speed and the direction of the vehicle, respectively. Further tests involved ultrasonic and IR distance sensors to intercept obstacles or human gestures nearby.

In terms of software, as students were not very familiar with textual programming, a considerable amount of tasks was done via the Ardublock visual programming tool, for Arduino related tasks, and via the MIT App Inventor environment, for smart phone related remote control tasks over Wi-Fi. The Arduino unit and the Raspberry Pi unit on the robot are communicating via suitable serial commands.

A good practice being followed was to use a separate power source (e.g., a power bank) for supplying the controlling circuit, as the motors have a quite “crude” behavior that sometimes results in sudden voltage drops on the main battery units supplying them.

4. Evaluation and Derived Enhancements

The modular nature of the experimental robotic layout development allowed for an educationally meaningful and very detailed description of the progress steps during the testing process. More specifically, according to the initial implementation involving two stepper motors to move the robot, it was observed/verified that these over engineered motors had a very high torque without requiring a built-in revolution reducer, they allow easy and precise movement determination, but they consume too much power and produce a lot of heat. Indeed, while the robot was powered at 8V, the stepper motor system consumed 2.0A at fast speed, 2.8A at medium speed and 3.1A at low speed. Its maximum consumption was at a standstill, while any increase in motors' load did not significantly increase the power consumption. Speeds being achieved, varied from 0.25ms^{-1} to 0.75ms^{-1}, that where similar to these of a walking man, as expected. The pulling force of the robot was about 2.5kg and its weight about 4kg. The cost of the whole robot was below 125€.

The powering issues lead the working team to replace the stepper motors with simple, brushed DC motors that have a much lower consumption which follows the load changes in a progressive manner. As a tradeoff, these DC motors require a feedback control system, to provide accurate operation, and thus such a mechanism was added, using photo interrupters fixed around the driving sprockets. This feedback mechanism configuration allows for a timer granularity at the order of 0.1s, which is not ideal in terms of responsiveness but, from educational aspect, allows for a clear inspection of robot's speed fluctuations during the speed correction process. For better results, a more aggressive integral speed correction schema was adopted for actual speeds lower than the target speed, while a less aggressive schema was adopted for speeds higher than the target value. Furthermore, the robotic vehicle was enhanced by incorporating a direction stabilization mechanism, based on data fusion of signals provided by a nine-degree of freedom IMU/compass data unit fixed on the top of the robot and connected with the Arduino via an I2C interface. For better matching the stepper motor counterpart characteristics, the two brushed DC motors had to be slightly over-voltaged (using 16V instead of 12V) so as to provide better torque and speed. Under the later setup, the system consumed, without load, at a low speed 0.14A, at average speed 0.16A, and at high speed it consumed 0.18A. In the case of operation under load at high speed, it consumed 0.32A with low load, 0.48A with medium load and 0.80A with high load. The vehicle's electronic system (microcontroller and motor driver circuits) consumed about 50-60 mA to operate, a comparatively small quantity that should be added to the abovementioned calculations. Most of the remote interaction scenarios have been carried out through Wi-Fi (Wi-Fi, 2019) interfaces, while some of them involved LoRa (LoRa, 2019) interfaces, to extend the effective controlling distance. In order to host the LoRa shield a second Arduino Uno unit was fixed on the robotic vehicle, instead of the Raspberry Pi unit. The adoption of the LoRa protocol for controlling the robotic vehicle demanded a custom Arduino based remote control unit, using a second LoRa shield at the user's end. The top left part of Fig. 2 provides a detailed view of the discussed enhancements involving brushed DC motors, photo interrupters, IMU/compass sensors and LoRa radio.

More ambitious enhancements involved motors of higher torque (i.e., more than the double), larger batteries and required the replacement of the initial motor driver (L298 chip) with an improved circuit, based on MOSFET type transistors and thus being able to handle higher currents with lower voltage drops. This layout allowed for greater wheels (of about 25cm in diameter) to be fixed on the chassis. Added to that, a small solar panel unit has been adapted on the top of the robot. This 15W solar panel was able to deliver at about 0.8A at 18V under good sunlight conditions, amount that could assist and charge the batteries. The top right part of Fig. 2 depicts the abovementioned robot's enhancements in size as well as the solar panel assisting the vehicle. The case depicted in the bottom part of Fig. 2 refers to a vehicle variant intended to pass over the young plants, mainly for inspecting and spraying them with fertilizers or for killing the weeds. Strong motors, big wheels and two solar panels are present in this layout. The controlling logic remains the same.

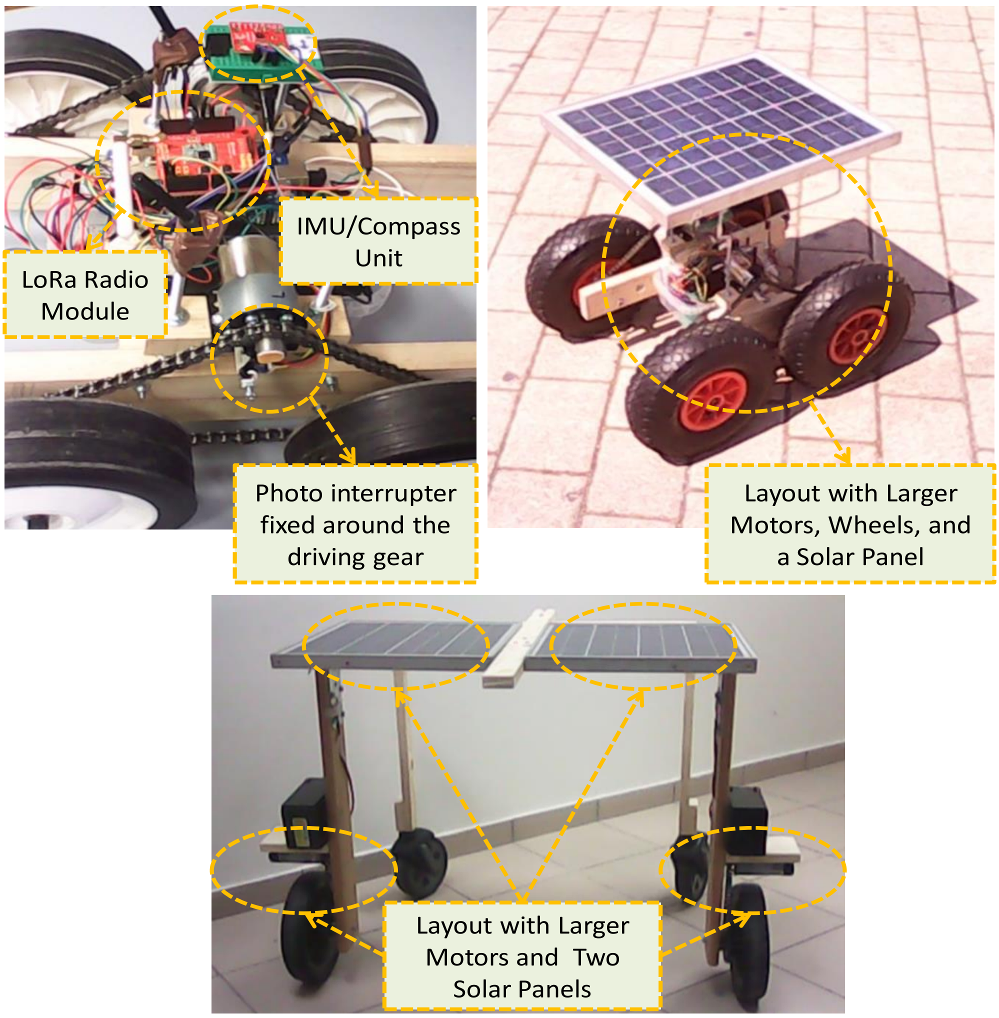

Figure 2. Enhancements involving feedback mechanism for DC motors, IMU/Compass unit and LoRa shields for Arduino (top left). Further enhancements involving solar panel assistance and bigger motors and wheels (top right and bottom)

5. Conclusions and Future Work

This paper highlighted the trials being made to design and implement electric robotic vehicles, in scale, in a cost effective manner, using metal, wood, recyclable materials and small motors, in order to aim students to catch up with the rapid technological advances in the agricultural era. Experimental configurations involved different motor types and controlling units. Brushed DC motors along with Arduino based controlling units form a cheap but educationally fruitful schema. By using a simple photo interrupter based speed feedback mechanism as well as IMU/compass modules it is possible to understand the fundamentals of automatic and remote control and proceed with code improvements that lead a more adaptive behavior. Both visual and textual programming environments were used to properly program the robot. In terms of remote operation, tests with LoRa interfaces provided an effective solution for increasing the controlling distance of the robot while keeping the power consumption at a low level. Energy consumption for the different configurations was studied, as well as solutions involved assistance by small solar panels.

The overall configuration, although initially targeted at educational goals, can easily be adapted to provide “real-world” solutions. For this reason, characteristic derived robotic layouts and the corresponding indicative use scenarios were also presented. Plans for the near feature involve further experimentation with the derived robotic vehicles, in larger and more robust electro-mechanical layouts. Furthermore, as LoRa interfaces drastically extend the effective controlling distance, more sophisticated methods for monitoring the robotic vehicle will be investigated, including fusion with GPS data or incorporation of machine vision techniques.

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SOIL ORGANIC CARBON ESTIMATION WITH THE USE OF PROXIMAL VISIBLE NEAR INFRARED SOIL SPECTROSCOPY

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ABSTRACT

Soil is an important natural resource, thus monitoring soils' condition in an efficient and quantifiable way is considered of great importance for site specific management practices. However, soil properties estimation is a laborious procedure that entails great amount of cost and time. To address the need for soil information at large scales, proximal sensing applications are considered as an alternative to analytical wet chemistry. In particular, soil reflectance spectroscopy in the visible and near infrared region (400-2500nm) has been evaluated with promising results. The use of proximal sensing techniques for rapid in situ applications comprise sensors mounted on tractors or at a handheld mode. Soil organic carbon (SOC) is the most widely investigated soil property due to its significance as it affects most of the processes related to soil functions and has presented good correlation with electromagnetic radiation. This work aims to provide a short review of proximal sensing techniques for SOC estimation. It was found that although results have been very promising there are still challenges to be addressed concerning factors that affect measurements i.e. soil moisture and soil roughness.

Keywords*:* proximal sensing, soil organic carbon, soil spectroscopy, VNIR-SWIR***.***

1. INTRODUCTION

Soil can act as a sink of greenhouse gasses (GHGs) through carbon sequestration, or as a source of carbon based GHGs depending on anthropogenic management factors. To that end, soil organic carbon (SOC) is recognized as a significant component affecting climate change adaptation and mitigation (FAO, 2017). Therefore, the need for recording and mapping its spatial distribution has gained great interest. Still, the assessment of SOC changes lacks in commonly accepted estimation methods, relevant data needs, and appropriate modeling approaches that provide consistent, comparable and accurate data to assist in decision making (Jandl *et al.*, 2014). Common analytical methods include dry and wet combustion, while in the past decade remote sensing applications, laboratory and proximal spectroscopic applications are being evaluated as more rapid and non-destructive techniques. Proximal sensing involves in situ measurements with sensors that are in close proximity with soil at approximately two meters (England *et al.*, 2018). These technologies concern either on-the-go sensors mounted on tractors or hand-held instruments that can be used for site

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specific management and variable rate applications in the field (Christy, 2007). Any on-the-go sensor is desirable to have certain specifications to provide reliable soil measurements that can be summarized as follows: (i) to be free of residues for every new measurement, (ii) allow data acquisition irrespective of the mode, (iii) permit the extraction ofsoil samples efficiently when necessary, (iv) present an adequate volume/mass of soil in a sufficient range of the sensor and (v) perform consistent measurements (Sinfield et al. 2010).

Reflectance spectroscopy is used thoroughly in proximal sensing. An asset of this technique is that several soil properties can be simultaneously measured with a single spectrum acquisition, while common electric or electromagnetic sensors are usually manufactured to measure a specific variable (Wetterlind, Stenberg and Rossel, 2013). However, in situ soil reflectance spectroscopy applications require proper environmental conditions and various pre-treatment methods to mitigate the effect of moisture content, soil roughness and vegetation cover (Nocita *et al.*, 2013).

In this study we discuss indicative studies from the past decade that used proximal sensing techniques for SOC or soil organic matter (SOM) estimation.

2. Soil organic carbon estimation with proximal sensing techniques

Continuous monitoring needs in the agricultural domain have led to the development of in situ soil sensors for rapid, cost-effective and real-time data acquisition that can provide high resolution maps. Kodaira and Shibusawa, (2013) upgraded a prototype real-time soil sensor (RTSS) (SAS 1000, SHIBUYAMACHINERY Co., Ltd.) that was subsequently mounted on a tractor. The RTSS had a sensor unit, a touch panel, a soil penetrator and a set of probes. The unit of the sensor comprised of a computer, a halogen lamp, a micro couple-charged device (CCD) camera, two spectrophotometers with spectral range from 350 to 1100nm and 950 to 1700 nm respectively, and a differential global positioning system. The sensor was designed to acquire spectra at soil depths from 0.05 – 0.35 m and the spectral data were acquired every 4 seconds. The speed of the tractor was 0.56 m s^{-1} similar to the speed needed for some field operations. After each measurement by the RTSS, two soil samples were taken from the same point resulting in 144 samples from an area of 8.94 ha. Results gave an accuracy of R^2 = 0.90 for SOM and the density of spectral acquisitions was adequate for the development of high-resolution maps. There are also commercialised sensors available. Kweon et al., (2013) used the OpticMapper™ from Veris Technologies in a study for SOM estimation that was held in 15 fields of total area 551 ha with wide variation in soil types and SOM concentrations. The specific sensor acquires spectra at two wavelengths (660 and 940 nm) for SOM and six coulter electrodes for cation exchange capacity (CEC) estimations. The measurements were made at a 4-cm depth and with a speed of 2.78–4.17 m s^{-1}, resulting in approximately 150-200 data points per field To that end, a soil moisture sensor was proposed to be added. Results showed that predictions made from individual fields generally gave lower RMSE (0.04-0.91) and higher RPD (1.46-25.03) compared to the universal model (i.e. RMSE ranged from 0.20-1.24 and RPD 0.54-4.39).

Considering soil moisture content and soil texture as the most significant factors affecting the accuracy of a prediction model, Kuang and Mouazen (2013) aimed to estimate their effect on SOC estimations. They used an on-line sensor developed by Mouazen and Ramon, (2006) mounted on a tractor. The sensor had a spectral range of 305-2200 nm and penetrated soil at a 15cm depth. Model calibration and validation was made for processed soils, fresh soils and on-line measurements. It was observed that removing the moisture content (MC) resulted in better calibration models, while MC together with increased clay content resulted in deterioration of the models' accuracy. However, this was not the case for dry calibration models as clay content increased accuracy. Furthermore, they proposed that the most suitable field conditions for on-line measurements are when the soil is dry and the clay content is relatively high.

Knadel et al. (2015) evaluated a sensor data fusion using the multi-sensor platform (MSP) from Veris Technologies in two different fields to provide supplementary information about soils' condition (i.e. soil temperature and electrical conductivity). During field measurements it was shown that 15 calibration samples were adequate for a 14.6 ha field. For better model calibration along with the spectral data, electrical conductivity and soil texture were also used as predictors. Spectra at the range of 500 to 1073 nm had lower quality than the range of 1073 to 2130 nm. However, excluding them from model calibration did not improve the models' performance. Overall, the results for SOC estimation were improved by the use of sensor fusion.

Considering ambient conditions, Rodionov et al. (2015) enclosed a spectrometer in a dark chamber mounted on a tractor to achieve illumination independent measurements. The system was designed for bare soil measurements and was tested in two modes; continuous and stop-and-go. For model calibration they first estimated soil moisture according to Rodionov et al., (2014) and after selecting the appropriate model they proceeded to SOC estimations. It was observed that apart from MC, another factor that provided errors in SOC predictions were gravels due to their brightness. The continuous mode presented spectral discontinuities due to different integration times, though this effect could be eliminated by reducing the number of spectra per scan. The stop-and-go mode gave R^2 = 0.65, while the same samples with conventional laboratory spectral measurements gave R^2= 0.94.

Even though bare soil conditions are ideal for in situ measurements, during such measurements there is a high possibility that there will be either green vegetation or straw covers that may lead to overestimation of SOC (Bartholomeus *et al.*, 2011). Rodionov et al. (2016) in a combined field and laboratory study used the same spectra to distinguish SOC from photosynthetic and non-photosynthetic vegetation. To estimate the effect of vegetation fractional cover, the experiment was conducted under laboratory conditions where soil samples were placed in petri dishes and the degree of plants and straws was gradually increased (24 soil samples with 13 covering degrees). Straw cover was characterized by the Cellulose Absorbance Index (CAI) and green vegetation was measured by different known indices, such as the Normalized Difference Vegetation Index (NDVI) etc. The aforementioned indices were estimated and then subtracted from field measurements to prevent SOC overestimation. While the spectral response of straw was not very distinctive both the use of CAI and NDVI were recommended to be utilized. Measurements were performed with a tractor driven closed chamber developed by Rodionov et al., (2015). For model calibration, MC and roughness were also accounted prior the evaluation of the straw and green vegetation influence. Although this study confirmed the overestimation of SOC content with the presence of green vegetation and straw coverage, the proposed method gave moderate predictions with R^2= 0.58-0.66.

There are cases that the use of a single sensor is not adequate for estimating soil properties (Ge, Thomasson and Sui, 2011). To that end, Viscarra Rossel et al. (2017) developed a sensor fusion the integrated Soil Condition Analysis System (SCANS). The experimental site was a cattle grazing farm from were 150 soil cores were extracted. For spectroscopic modelling, the Cubist algorithm combined with the RS-LOCAL algorithm was applied to better utilize local soil spectral libraries (SSLs). The external parameter orthogonalization (EPO) algorithm was used to eliminate the effect of water. Results were promising with SOC showing better accuracy (R^2 = 0.83).

Most studies mainly tried to mitigate the effects of MC, whereas Franceschini et al. (2018) used the VNIR-SWIR Veris Spectrometer to correct the effects of external factors and particularly those related to sensor movement during spectral acquisition. In addition to EPO and direct standardization (DS), orthogonal signal correction (OSC) was also implemented for the purposes of the study. Field measurements were compared to laboratory measurements of un-processed soil samples, assuming that MC was approximately the same, hence any differences in the accuracy of predictions could be attributed to factors other than soil moisture. Nevertheless, results were substantially inferior indicating that factors like soil-to-sensor distance and angle, gravels or straws and changes in the illumination conditions, should also be considered.

To overcome the lack of field data and the laborious procedure of creating new SSLs for un-processed field samples, Kühnel and Bogner (2017) evaluated the use of the synthetic minority oversampling technique (SMOTE) to directly use in situ soil spectra. The technique gives extra weight to existing soil samples and generates new synthetic spectra and by that mean it increases the number of existing datasets. Overall the synthetic spectra provided more similar spectral response with in situ spectra rather than those from dry, sieved samples.

There are also portable instruments able to be used for in field applications using a contact probe. Gras et al. (2014) tested seven different practices in the field using the ASDLabSpec 5000 spectrometer (Analytical Spectral Devices, Boulder, CO, USA) to conclude which approach provides the most accurate SOM predictions. These procedures were applied either directly to the soil surface (in cores extracted with an auger) or to clods crumbled from the cores and no external validation was performed as the aim was to select the most efficient approach for spectral acquisition. The most efficient approach for spectral acquisition was in raw core measurements with an RPD = 2.8. Cambou et al. (2016) collected soil samples with a manual auger and the spectral measurements were made to the outer core. PLSR model calibration resulted in R^2 =0.75 and R^2 =0.70 for SOC and SOC stock estimations respectively. It was noted that the accuracy of the results could be related to no compatibility between samples the spectral measurements were made and the samples sent for laboratory estimations.

3. Considerations about proximal sensors

In the previous section many considerations regarding the configuration and operation of proximal soil sensors with emphasis in mobile proximal sensors were presented. To address the effects of ambient conditions, the enclosure of the sensor in a dark chamber is suggested to minimize external light interferences. The sensor's distance from the ground and the configuration of the artificial illumination angle could affect the intensity and quality of the signal. Another aspect for consideration is the depth of the measurements as there are sensors that acquire the spectral signature from the top layer of the soil and configurations equipped with a soil penetrator that can achieve measurements at various depths. Most studies were conducted in bare soil conditions which are not always representative of large-scale real field conditions; to that end it is imperative to address vegetation cover effect which can lead to SOC overestimation. It was also highlighted that the mode of spectral acquisition i.e. stop-and-go or continuous also affects the quality of the measurements, as a continuous mode could lower the predictions adding excessive noise due to spectral discontinuities of different integration times and vibrations due to the vehicle's speed.

4. Conclusions

This paper has reviewed spectroscopic proximal sensing techniques for SOC and SOM estimation. It was observed that the sensors configuration and the mode of spectral acquisition plays a significant role to the accuracy of the generated models. Soil moisture levels should be taken into consideration especially when different field data are combined or when a universal calibration model is created, as it significantly affects the soils spectral response. An integrated soil sensing approach with complimentary set of sensors for quantifying different soil properties could provide additional information to improve the model's accuracy. The selection of the modelling approach varies among different studies and mainly depends on data availability and entails the use of simple linear regression to machine learning techniques. Still there is not a commonly agreed protocol for in situ spectral measurements that could provide reliable and comparable with other studies results.

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