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The Interplay between Informal and Formal Bylaws in Supporting Sustainable Crop Intensification in the Uganda Potato Production System

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Abstract

The study assessed the interplay between informal and formal bylaws in supporting sustainable crop intensification, using a case of potato crop production in southwestern Uganda. The study used a descriptive case study design to understand and accurately describe the experiences of farmers in the potato crop subsector in the region. This involved mixed study approaches that ensured coded meaning of consistent responses to the study, and descriptive statistics facilitated sequential understanding of findings and how each related to one another in respective themes. The numerical scores enriched the findings by authenticating the qualitative outcomes of the study to minimize bias. The study used review of documents and literature; six Focus Group Discussions; and 22 Key Informant Interviews to gather diverse experiences of respondents patterns of responses, the main factors or categories, and key responses under every category. The Study found that the greatest informal bylaw was eucalyptus growing (50 percent), followed by permission to graze (18 percent), and control damping (18 percent). The widely represented formal bylaws had a comparatively lesser role in supporting SCI, although with greater emphasis on quality seed (22 percent). Formal bylaws were stronger at setting clear boundaries between users and resources (18 percent), users having procedures for making own rules (11 percent), regular monitoring of resources and users (15 percent), issue sanctions (16 percent), conflict resolution (15 percent), and coordinated activities (3 percent) than informal bylaws. The major benefits for operating as institution were the collective strategy for the market (26 percent), which was less to guarantee sustainable livelihoods for farmers. Individual farmers were driven by desire for faster benefits (13) and preferred following own rules (12 percent). There was more emphasis on market access, regardless of the nature of produce output (35 percent), whether the market worthy or not, and less on environment sustainability. The informal and formal bylaws are separate but united for a common purpose of intensifying potato crop production. Nonetheless, even when combined, they are not strong enough to support SCI. There is a need to strength bylaws on soil and water conservation, improved and quality seed potato and environment sustainability to support SCI, which provide the basis of greater markets and sustainable livelihoods.

Keywords: Uganda, sustainable crop intensification, formal bylaws, informal bylaws, policy implementation, potato

1. Introduction

Globally, more than 118 million people faced hunger in 2020 than 2019 due outbreak of Covid19, which destabilized economies (Food and Agriculture Organisation, International Fund for Agriculture Development, United Nations Children Fund, World Food Programme, and World health organization, 2020). By addressing Sustainable Development Goals (SDG) 2: zero hunger, the global population gets closer to meeting higher goals (United Nations Industrial Development Organization, 2020). This study targets global efforts towards inclusive and sustainable development through applicable of bylaws to intensify potato production in spite of the scarce and diminishing value of land resources to supply adequate food requirements for the growing population

(Otsuka and Place, 2014; Pretty, 2011).

According to the new institutionalism theory by North (1990), the evolution of institutions involves formulating group rules and norms, which direct behaviour towards the fulfilment of a specific goal. Bylaws evolve out of experiences and lessons about how to conserve soil and water, ensure seed quality, handle crop yields, and access markets. Bylaws were written (formal) or unwritten (informal) (Yami et al., 2012; Helmke and Levitsky, 2004; North, 1990; Sanginga et al., 2009).

Therefore, the operationalization of bylaws-centered policies within socially-responsive institutions is most ideal for supporting SCI. Individual farmers may follow bylaws, bylaws-driven and institutionally-evolved policies, but remain reluctant to operate within social groups, farmers' associations, or institutions to achieve SCI. The bylaws evolve as simple rules developed and agreed to by farmers' associations to strengthen their focus, effort, and actions towards achieving SCI in the production of the potato as a cash crop. Classical studies have considered individual interests as ones that influence social interests towards growth and development (Boserup, 1965). Individual farmers tend to be aware of the local bylaws or bylaw-driven institutional policies for sustainable farming, but prefer to operate outside farmers' groups or associations. The loosely coordinated collective individual responsibility towards implementations of bylaws to support SCI is most consequential and sustainable, where each farmer works for the general good of everyone else. Ostrom (1990) presented the eight design principles of effective institutions through loose and fair management of people to respond towards a set strategy, such as setting boundaries, harmonized costs and benefits, setting procedures for making rules, regular monitoring, conflict resolution, respect for rights, and coordinated activities of associations. This study explored ways for achieving SCI through the procedural application of informal and formal bylaws to support institutional policy development in farmers' association within potato production system to sustain economies and livelihoods of people in SWU.

The formulation of evidence-based policies within institutions relies on stakeholders' opinions and reports on ongoing implementation processes (Strehlenert, et al., 2015). This creates and facilitates a system of checks and balances during the implementation of the bylaws and bylaw-centered policies to support SCI. According to (Yami and Van Asten, 2017), policy-driven institutions contribute to SCI in Eastern Africa. However, exiting agriculture policies are operationalized across production sectors. Hence, they are not specific to guiding production in the potato sector, which has unique needs. They also focus on output rather than sustainability beyond production benefits like food and nutritional security, employment, reducing income inequality, stimulating investments and growth of local and international commerce (Ministry of Agriculture, Animal Industry, and Fisheries, 2013).

Thus, the influence of bylaws (informal and formal) in their formulation for the sustainability of agricultural policies is not articulated. For a long, the studies on SCI have emphasized the biophysical factors rather than institutional and policy-driven bylaws (Vanlauwe et al., 2014; Schut et al., 2016). This study argues that policies applicable in supporting SCI are those that are adapted to existing bylaws and operationalized within institutions for them to be effective and sustainable at intensifying potato crop production. SCI is premised on four key aspects: 1) necessity to increase production, 2) higher yields on smallholder farmland, 3) minimise environmental costs and maximise sustainability, and 4) appropriate agricultural techniques (Garnett et al., 2013). The rising demand of potato crop in urban areas has led to the economic boom in rural potato growing areas (National Agriculture Advisory Services, 2020). SCI strategy is, thus, the answer for the population to cope with demand. However, there is limited data about the role of bylaws in supporting SCI in potato production. While institutions provide a viable framework for managing common-pool resources and support intensification of potato crop production feasible, there is little knowledge about how their regulatory frameworks are developed and implemented to intensify potato production, ensure the efficacy of such implementations, and demonstrate the influence of bylaws in formulating the operationalized policies within institutions. It is also speculative to suggest that institutional weaknesses influence individuals to operate outside farmers' groups. This study contributes effective ways through which bylaws strengthen policies and institutions to support SCI, beyond the current focus on biophysical interventions, without which sustainable livelihoods of people can remain a dream. The study assesses the interplay between informal and formal bylaws in supporting potato crop intensification in SWU, by assessing the relationship between informal and formal bylaws, individual farmers and institutional framework for implementing bylaws, and the overall effect they have on SCI.

2. Conceptual and Analytical Framework

The conceptual framework is developed from analysis of the theoretical perspectives of the study, especially Boserup (1965); Ostrom (2009); Cox, Arnold, Villamayor-Tomas (2010); and Xie, Huang, Chen, Zhang, and Wu

(2019), which positions individual merit and socioeconomic perspective-based informal and formal bylaws, functioning within the institutional framework and individual farmers' behaviours for supporting SCI in potato cropping system in SWU. According to Ostrom (1990), effective group management based agreeable mode of operation within networks of farmers' entities, improved response towards a group goal. Boserup (1965:14) observed that the growing population was inevitable and irreversible, which implied the need to focus on improving soil fertility to increase production and ensure food security, through practices like the application of animal manure, short fallow rotations, terracing, and intensive farming in areas with dense population. However, Boserup's work has been criticized for simplifying the dynamics of agricultural systems and considering population pressure as the sole driver of change, whilst ignoring the role of local policies, markets, and institutions they functioned under, such as governments and environmental conditions (Djurfeldt et al., 2005; Brookfield, 2001).

According to The new intuitionalism theory (NIT), the formal and informal laws are key to institutional change. An adaptive institutional framework readily adapts to changing circumstances and such frameworks encouraged decentralized decision making and enable society to maximize opportunities for problem-solving during the change process (North, 1994:367; 1990:81). The change is guided by humanly-devised informal and formal rules or constraints, which influenced interaction towards a collective need or goal (North, 1990:3,4). This study details the role of institutionalism versus individualism. To varying extents, potato farmers tended to be either institutional or individualistic in their approach to potato production in SWU. Thus, the study assesses the interplay between informal and formal bylaws and their effect on individual and institutional frameworks for developing and implementing bylaws to intensify potato crop production in SWU. In this study, achieving SCI (DV) is dependent on the interplay between informal and formal bylaws (IV), and operationalized as policies in institutions (farmers' associations) and individual behaviours (MV) to support SCI (Figure 1).

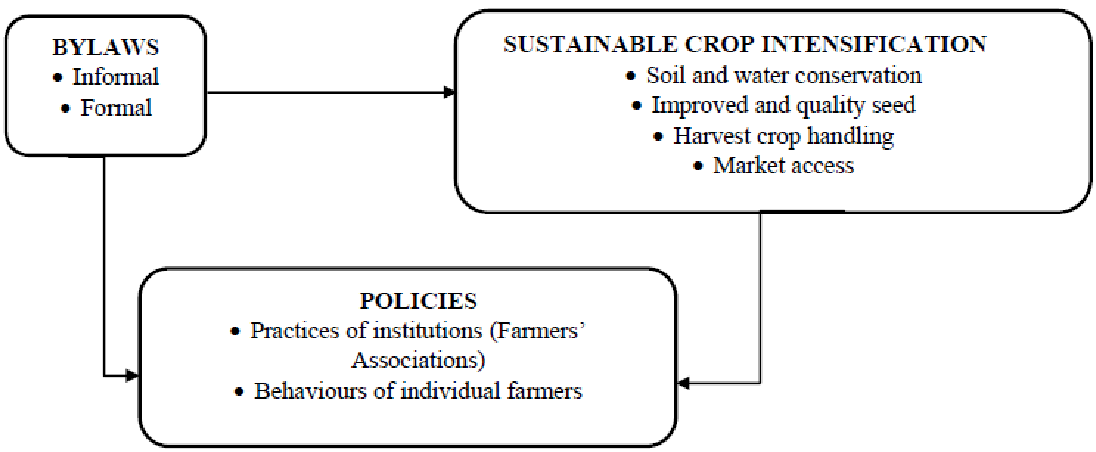

Figure 1. Relationship between study variables

3. Methodology

3.1 Area of Study

The study covered three areas, namely; Muko, Kamuganguzi Sub-counties (Kabale District) and Bubare Subcounty (Rubanda District) in southwestern Uganda (SWU) (Figure 2). These areas are highly populated, with scarce land resources, where SCI has the potential to contribute to sustainable livelihoods by intensifying potato crop production and conservation of the environment by communities in the region. They are popular potato growing areas in Uganda, which face a number of challenges because of the changing land tenure system, diminishing soil productivity, and unpredictable seasons. Highland areas where the study areas are located are susceptible to soil erosion, high population growth, land fragmentations, and overuse of land. Soil conservation practices were largely traditional, compromising mainly of crop-rotation, intercropping, and use of cover-crops, instead of terracing and use of trenches, which should be the commonest SCI interventions, owing to the mountainous topography of the area (Fungo et al., 2011:251, 255, 257). The study areas were chosen as they presented suitable considerations for the application of relevant bylaws and bylaw-centered policies to reinforce best practices in SCI.

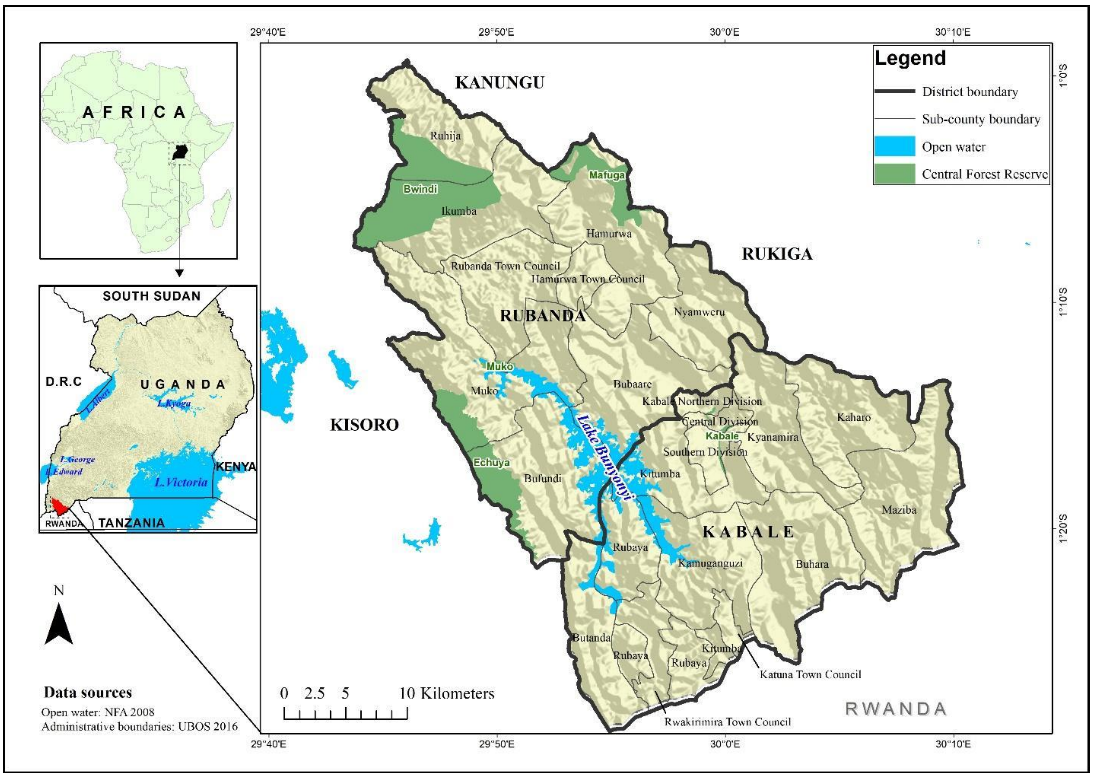

Figure 2. The map showing the study area in southwestern Uganda

3.2 Study Design

The study used descriptive case study design for in-depth understanding and correct explanations of effect relationships between variables of subjects in their natural setting (Sullivan-Bolyai and Bova, 2021). The study confirmed validity by comparing observations from more than one set of data since qualitative-based studies are most prone to bias. This study was able to understand and explain farmers' behaviour towards SCI

3.3 Sampling Methods

The study used a purposive sampling of potato farmers and reports on existing bylaws in selected study sites (Gentles, Charles, Ploeg, McKibbon, 2015). Experienced groups or associations and individual farmers represented the larger population of farmers in the region.

3.3.1 Criteria for Selecting Participants

The study identified specific characteristics of participants to show their relevance in providing accurate data. Harrison (2017) suggested that sources of data ought to be reliable for them to be included in the study. The sources of data were farmers, leaders of farmers' associations, and technical officials in the selected areas of study. The study provided 5 key characteristics of participants. This shows their relevance in informing the study so that consistent, most accurate, and reliable data could be obtained from them (Table 1).

Table 1. Criteria for recruiting participants

No.	Participants	Non-participants
1	At least 2 years farming experience	Non-farmers or dis-engaged former farmers
2	18 to 75 years of age	Below 18 years of age
3	Male or Female	Lacking right to own production land
4	Farm owner	Lacking decision making influence on farming
5	Resident of the areas studied	Living outside the areas of study

Source: Primary Data

3.4 Data Collection Instruments

The data collection instruments used in this study were focus group discussions (FGDs) and key informant interviews.

3.4.1 Focus Group Discussions

The study conducted six focus group discussions (FGDs). Two FGDs were conducted in each of the sub-counties of Kamuganguzi (Kabale District), Bubare and Muko (Rubanda District) to minimize bias while gaining richer data from each of the stratum. Hennink, Kaiser, and Weber (2019) recommended at least two focused discussions for each of the stratum. This justifies decisions made by the study to conduct two focused discussions in three different locations (six FGDs). The FGDs consisted of 6-8 participants, and semi-structured, and open-ended questions. The discussions were simultaneous and in-depth discussions for homogenous groups of people, such as members of the farmers' associations. The semi-structured questions were informed by standardized tools for determining strong institutions and specific bylaws that supported SCI. Research has shown that four FGDs were appropriate sample for well-conducted group discussions. More than 4 group discussions (six in this case) provided much strong and reliable data to inform the study. Although four FGDs were sufficient to recognize patterns in the data, more group discussions strengthened comprehension by a researcher (Hennink et al., 2019). The use of FGDs saved time by meeting more than 6 participants in a single or few sessions rather than arrange 20 to 30 sessions for equal number of individual farmers. The use of FGD was most suited to the institutional-social aspect of the study. However, there was a tendency of dominance of specific participants despite efforts to spread participation among all of them. The dominant participants tended to dictate a specific data trends against the possibility of alternative views for overall consideration in the study. The use of collaborating data collection methods like key informant interviews (KIIs) improved validity of data that fell short of quality in FGDs due to impact of domineering participants on the general outcome of the study.

3.4.2 Key Informant Interviews

The study used key informant interviews (KIIs) to collect data from leaders of policy-led institutions, which consisted of representatives of farmers' associations and technical local government officials in the selected areas of the study. The total number of individual participants was 22. There is a consensus among researchers that for descriptive case studies, 12-20 participants were adequate representation of the population size (Kim et al., 2017; Yin, 2014). Standardized tools or frameworks for assessing the strength of institutions and specific bylaws for achieving SCI informed the interview questions. The study selected participants to represent the study population because of their positions of responsibility, practical experiences, and expertise on potato crop production in the region. The KIIs sought expert opinions on matters pertaining to strength of institutional governance and impact on involvement of grassroots population or movements in supporting SCI. This facilitated the understanding of the influence of bylaws in institutional designs and policies in supporting SCI. The use of KIIs improved the quality data collected from FGDs, which often lost quality data because of limited participation by some discussants, or their misrepresentation by most active others.

3.5 Analysis

The study used existing frameworks for assessing strong institutions and specific bylaws (informal or informal) that effected farmers' behavior in order to support SCI. Burnard et al. (2008) explained that deduction analysis used existing structures to analyse data. In this study, frameworks for assessing effectiveness of institutions and existing bylaws guided analysis of data and generalisation of findings. Themes developed through repeated observations of response to specific thematic questions modified from standardised frameworks, such as the eight design principles of effective institutions and existing bylaws (informal and formal). Henceforth, deduction analysis led to holistic observation of unique and varying responses of participants (Kohlbacher, 2005). The themes are a collection of coded meanings, where each code represents a specific meaning (Sutton and Austin, 2015). In addition, the study assigned each specific meaning a label (a worded or qualitative meaning). Separate labels applied to positive and negative responses. Each label symbolised a specific pattern of behavior under each major pattern or theme. Minor behaviour responses were included for general understanding of different elements that featured in the study.

The study assigned numerical codes, such as 1, 2, 3, 4… to each recognised pattern of behaviour at different levels, whether major or minor labels. The study allocated different codes to repeated responses, sequentially, to show how much emphasis-related ones (responses) had. The sequences of numerical responses for the respective labels were assigned a frequency number (number of times participants responded to a single case). This facilitated ranking of responses according to extent of emphasis in descending order. The ranking of labels for each research question, major labels or themes, minor labels or themes, and sub-minor labels or themes marked the end of descriptive qualitative analysis.

However, in this study, descriptive statistic's refined understanding of qualitative findings and clear comparison of findings from two data sets (FGDs and KIIs), whose respective findings were generalized as summary findings for the entire study. The admission of descriptive statistics, which is, otherwise, quantitative method, marked the use of mixed methods of research by converting frequencies of labels into percentage scores. This facilitates description of findings basing on the extent of percentage scores and comparing data for each of the research questions. The study considered only major labels for every major theme as summary findings since responses were numerous and extensive to be presented as such. Nevertheless, understanding of details of farmers' behaviors was vital part of the study because it informed research of major areas of policy interventions and specific areas of strengthening and appreciation or rewarding.

Further, for each of the research questions, summary tables show major themes and labels of specific codes under them in the first column, frequencies in the second column, and percentage scores in the third column, while the first upper row indicates headings for the respective column data details (categories). For coherent computation and tabulation of data, the study utilised Excel Spreadsheets to generate the descriptive statistics as integral part of findings.

3.6 Ethical Consideration

The research proposal was registered, peer-reviewed, and approved by the National Research and Ethics Committee at the Uganda National Council for Science and Technology (UNCST). The study sought consent approval of respondents before commencement of interviews.

4. Findings of the Study

4.1 Description of Stakeholders in SCI of Potato Crop Production

The stakeholders in SCI are government of Uganda and its agencies, Ministry of Agriculture Animal Industry and Fisheries (MAAIF), Local Councils (LCs), Uganda Police Force, extension workers, parish chiefs, district agricultural office, and national agricultural research organisation (NARO); community, farmer's association, Church, Uganda national seed producers' association); media; and international non-government organisations, international fertilizers development corporation (IFDC). Their roles are; decentrialisation of services, supervision of agricultural programmes, arbitration of cases, advisory and training services, implementation and monitoring of government programmes, technical support to farmers, innovation in viable seed varieties, participation in community-based services, pooling and efficient management of agricultural resources for sustainable livelihoods, acting as a platform for mobilization of communities for development, platform for creating awareness, collaboration and funding, as well as production of appropriate and quality fertilizers (Table 2).

Table 2. Shows description of stakeholders' in potato crop production

No.	Name	Role
1	**Central Government (Government of Uganda)**	Decentralisation of services
1.1	Ministry of Agriculture Animal Industry and Fisheries (MAAIF)	Supervision
1.2	Local Councils (LCs)	Arbitration meetings
1.3	Uganda Police Force	Enforcement
1.4	Extension Workers	Advisory and training
1.5	Parish Chiefs	Implementation
1.6	District Agricultural Office	Technical support
1.7	National Agricultural Research Organisation (NARO)	Quality seed varieties
2	**Community**	Community-help activities
3	**Farmers' Association**	Pooling and managing resources
4	**Church (Catholic Church)**	Mobilisation platform
5	**Civil Society**	Advocacy and campaigns
5.1	Uganda National Seed Producers' Association (UNSPA)	Quality seed production
5.2	Media	Awareness platform
6	**International Non-government Organizations (INGOs)**	Collaboration and funding
6.1	International Fertilizers Development Corporation (IFDC)	Quality fertilizers

Source: Primary Data

4.2 The Relationship between Informal and Formal Bylaws in Supporting Sustainable Potato Crop Intensification in SWU

The study found a greater influence of formal bylaws in supporting SCI than informal bylaws. The basis of this finding was the greater representation of documented formal bylaws. Overall, there was a greater concern for growing of eucalyptus and the need to discourage it (50 percent), followed by permission to graze (18 percent), and control damping (18 percent), while the widely represented formal bylaws had a comparatively lesser role in supporting SCI, with greater emphasis on improved and quality seed (22 percent). Most of the formal bylaws were below 10 percent score, such as ridge tillage, control of diseases, control grazing, digging channels, creating contours, selling in weight (kilograms), and fining outlaws. Nevertheless, both informal and formal bylaws were mutually reinforcing in supporting SCI. Hence, implementation of both bylaws categories contributed to responses by farmers towards SCI. In Figure 4, the study assessed institutional strength using Ostrom's eight design principles of effective institutions. The greatest score related to harmonized cost and benefits principle (52 percent and 22 percent for informal bylaws and formal bylaws, respectively) (Figure 4). Formal bylaws were stronger at setting clear boundaries between users and resources (18 percent), users having procedures for making own rules (11 percent), regular monitoring of resources and users (15 percent), issue sanctions (16 percent), conflict resolution (15 percent), and coordinated activities (3 percent) than informal bylaws. Hence, there was more compatibility with cost and benefits with informal than formal bylaws, although the latter proved most sustainable and comparably easier to influence behaviour of farmers to support SCI (Figure 3). Respondents from Kamuganguzi, Seed quality FGD (2018) confirmed the role of bylaws in supporting suitable potato crop intensification when they generally said:

> *"…we put up some of these bylaws so that we can get a better harvest because we said once you dig this trench when running water comes from up. Potatoes will be spoilt so once you put up your garden. You have to follow it up. So on such a bylaw, we as farmers have to implement it because you are the one liable to use it. The bylaws help us, and we love them very much because once you follow them the way we talked about them, even when you get a customer, and he comes into your seed potato store. He immediately appreciates before you even start bargaining because they will be looking well and are well protected, and so he will like them before you even talk to him."*

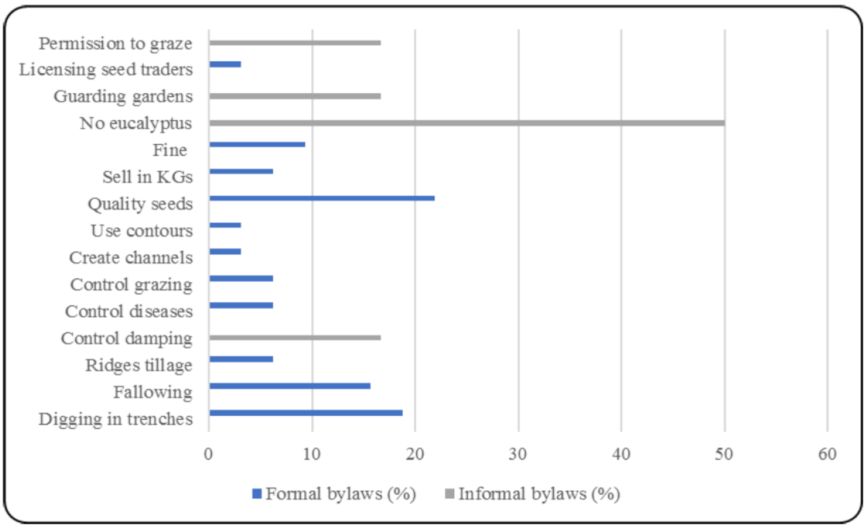

Figure 3. Shows relationship between informal and formal bylaws in supporting SCI

Source: Primary Data

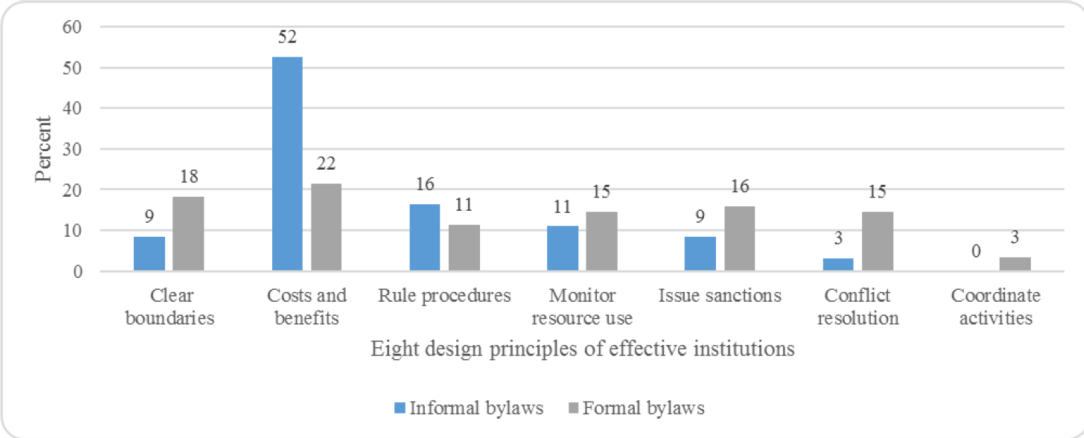

Figure 4. Shows assessment of institutions using the eight design principles of effectiveness

Source: Primary Data

4.3 What is the Role of Individual and Institutional Frameworks in Supporting Sustainable Potato Crop Intensification?

The role of institutions in supporting SCI in potato producing areas in SWU was most predominant in comparison of individual farmers (Figure 5). The major benefits for operating as institution were the collective strategy for the market (26 percent), which proved most challenging to individual farmers who opted to use small network of family members to market their produce. Institutional operations were involved in bargaining, buying produce, storing it until prices were favourable, and better prices. The individual farmers were renowned for believing in faster benefits by operating outside farming institutions, like farmers' associations (12 percent). Institutional capacities were still low on many aspects of sector development (less than 10 percent), such as mobilization of resources, record keeping, saving, conflict resolution, policy development and implementation, quality control, licensing seed producers, and administration. While working within the framework was more sustainable in terms of yielding socioeconomic benefits, high-quality potato production, and natural resources use than individualism (using individual knowledge and value system) to support SCI in SWU, highest institutional score of 26 percent was too small to attract individual farmers to join and benefit from market potential. Farmers incurred greater costs using formal bylaws to support SCI. Bubare Innovation Platform official (March 2018) observed:

> *"IFDC is doing training farmers, demonstration gardens, giving fertilizers and seed spraying pumps even has put up some storage facilities. Then we have NARO, which is also doing training. They move around certifying people like seed producers."*

> *"The committee for quality control, once they go to supervise, and they find that your garden is not looking well, on the seed column we will note. We make sure that these fields they want to plant in potatoes fields fit to grow potatoes for seed. How long have they taken without being used for potato growing or are they in the low land where floods or running water will be collecting. And this field, if our member is going to cultivate it, is he/she following those things or bylaws that they are telling us? … the seed he is going to plant; we have to investigate whether he got it from a known seed producer or a research firm."*

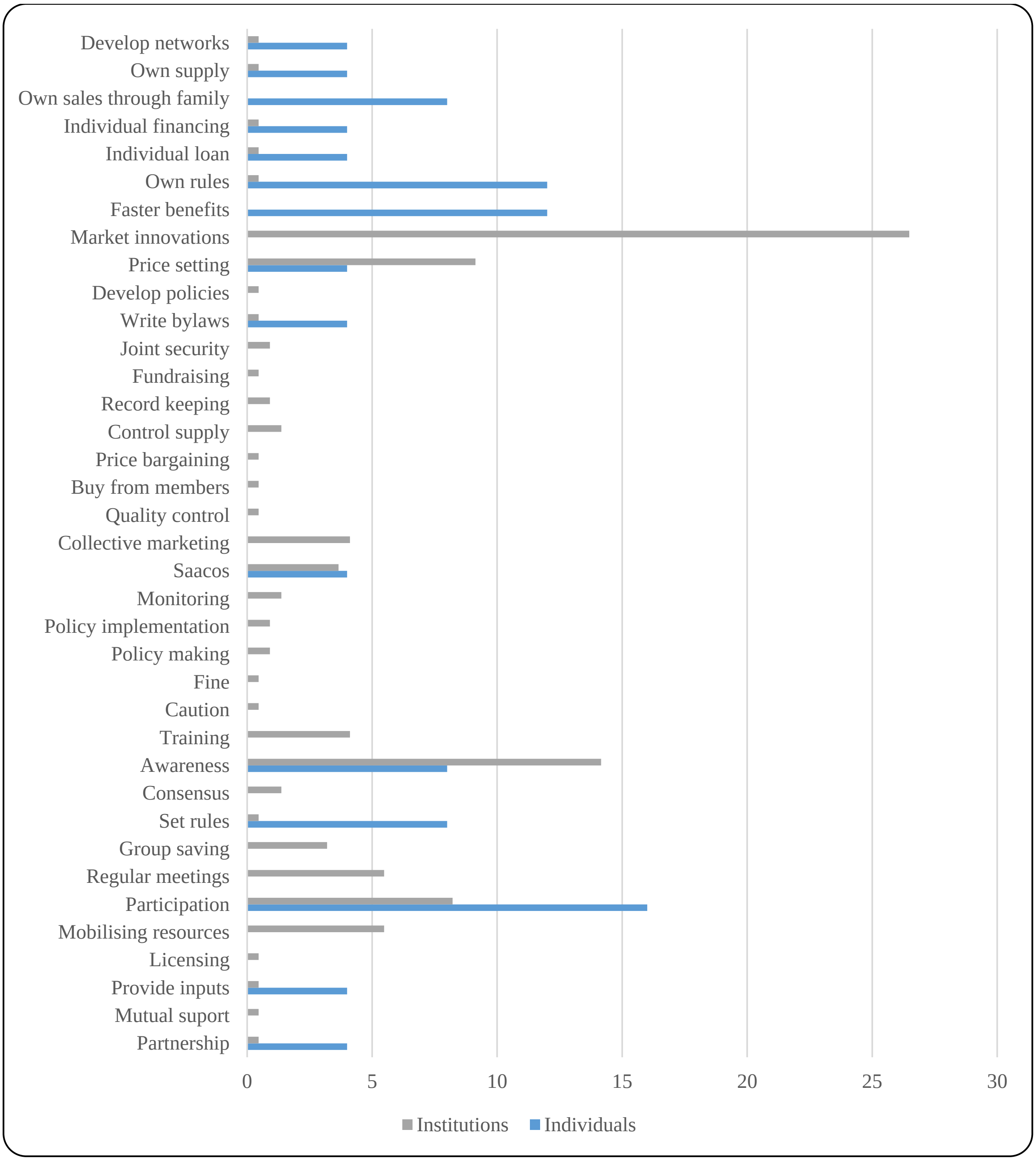

Figure 5. Shows individual and institutional roles in supporting SCI

Source: Primary Data

4.4 What is the Effect of Informal and Formal Bylaws on Sustainable Potato Crop Intensification in SWU?

The study found more emphasis on market access, regardless of the nature of produce output (35 percent), whether they are market worthy or not. The variables for SCI were least considered such as soil conservation in the use of fertilizers, equipment, packaging, transport, and price instability, because farmers do not find adequate motivation to commit to potato production, all which have scores below 10 percent, yet returns from the market are not impressive (35 percent). Hence, the bylaws have not been able to strengthen the response towards SCI (Figure 6).

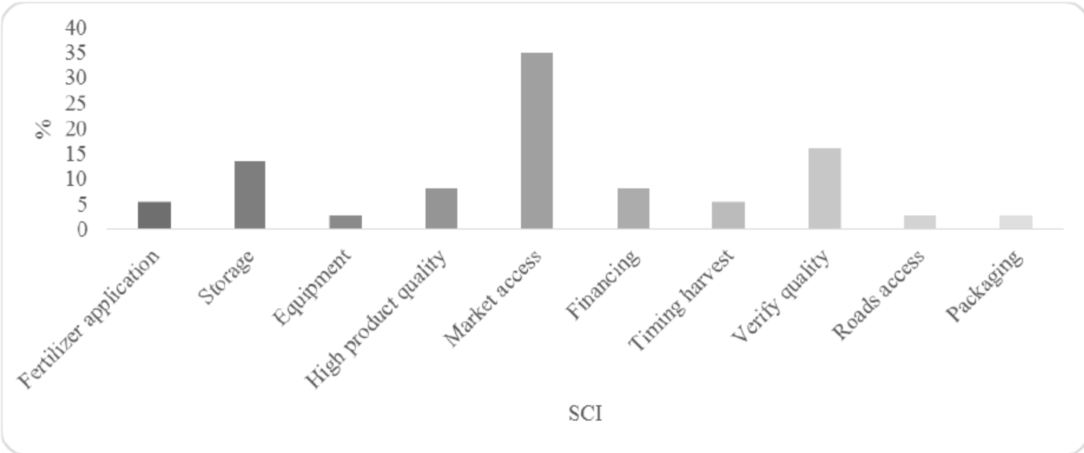

Figure 6. Shows effect of informal and formal bylaws on SCI

Source: Primary Data

5. Discussion

In this section, the study reflects on the results in relation to the literature review, as well as the theoretical and conceptual frameworks to confirm areas of agreement and disagreement and implications to the study. The discussion follows the order of presentations in the previous section (4.1), based on the key findings for each of the objectives provided to draw implications to scholarship on SCI in the potato cropping system. In the findings, the scores show a number of mentions and percentages to facilitate the description of the phenomena.

The study found expressed greater influence of informal bylaws with respect to no eucalyptus (50 percent), seeking permission to graze (18 percent), and control dumping (18 percent). Formal bylaws were widespread but less influential in boosting response towards SCI, with great focus on seed quality, which could not act in isolation without the functioning of other formal bylaws, which mostly were under 10 percent score. Costs and benefits were more harmonized under the influence of informal bylaws than formal bylaws (52 percent and 22 percent, respectively). However, formal bylaws showed greater strength at setting clear boundaries between users and resources than informal bylaws (18 percent. Formal bylaws were stronger at setting clear boundaries between users and resources (18 percent), users having procedures for making own rules (11 percent), regular monitoring of resources and users (15 percent), issue sanctions (16 percent), conflict resolution (15 percent), and coordinated activities (3 percent) than informal bylaws. The findings show separate roles of informal and formal bylaws in supporting the intensification of potato crop production, even when formal bylaws evolved from informal bylaws. That is from unwritten to written bylaws. This explanation originates from the new institutionalism theory by North (1990), which affirms that socialization of values to become social norms and bylaws to guide group behaviour in handling conflicts in using the limited natural resources to sustain livelihoods. The importance of bylaws, thus, remains central in sustainable potato crop intensification in SWU. However, they must be known to people they target for them to be meaningful, and be communicated regularly until expected behaviour takes root in the lives of farmers for them to passionately intensify potato crop production in the region.

The study finds a greater role of institutions than individual farmers in supporting sustainable potato crop intensification in SWU. The farmers enjoyed greater prospects operating within institutional framework than as individuals, because of the greater levels of efficiency associated with them, especially in terms of accessing better markets compared to individual farmers who sought faster benefits, instead (13 percent). Both demonstrated no concern for the sustainability of production and the environment. Research has shown SCI a very relevant way of transforming the socio-economic lives of people amidst escalating food security and livelihood challenges in the region. The study shows limited policy influence on SCI and negligible influence of bylaws on policy development within institutions, which is a basis of their strength in delivering their mandate. The institutions demonstrate gaps between their role and action in supporting the intensification of potato crop production. This explains why individual farmers re reluctant to join farmers' associations. This contrasts Yami and Van Asten works in 2009; 2017; and 2018 in support of institutionalising crop production as a way to intensify it. Particularly Yami et al. (2009), whose work focuses on sustainable management of the common-pool resource in the Tigray region in Ethiopia, acknowledge the role of local knowledge systems in the management of common-pool resources. These studies confirm that, for institutions to be effective, they must organically have evolved and incorporated grass-root bylaws as a basis of their regulatory frameworks in guiding and influencing stakeholders towards SCI. As opposed to the top-down approach, the effective roles of institutions are such that the bottom-up approach to decision making supersedes top-down other for sustainability good, especially when actors were well-coordinated to focus on SCI in their parallel functions towards the same purpose (SCI). The failure and weaknesses of institutions potentially drive away resourceful members, because of the lost trust and confidence that results from the poor coordination and limited progress of farmers' associations.

The effects of bylaws (informal and formal bylaws) and bylaw-based policies on SCI were limited in both scope and intensity, which undermine efforts towards food security, and socioeconomic transformation SWU. Unfortunately, the trend influenced SCI the same way such that direction farmers' perception and behaviour targets financial returns (35 percent) through market access rather than improved and quality seed, soil and water conservation, and environmental sustainability, which maintains and improves it. While SCI shows greater seed quality verification exercise, in practice, there is little that is done to guarantee seed quality. Even access to market proved below the expected one. The explanation for the low SCI is the weak bylaws and institutional framework for implementing them, which as Ostrom put it, they deserved better governance to be effective. Ostrom suggested eight design principles of developing strong institutions that can best support SCI, such as defining clear boundaries of the shared resource, negotiating for a system that reward members, making rules and decisions by consensus, monitoring vulnerability and overexploitation of resources, issuing sanctions for members, resolving conflict in just ways to the group, recognising minimum rights of members, and coordinating groups of the larger social systems (Cox, Arnold, Villamayor-Tomas, 2010; Sumane et al., 2017). This provides an insight into how effective to manage farmers' associations to best implements bylaws that are relevant to sustainable potato crop intensification in SWU. Walukano et al., (2016) made similar assertions related to seed quality that investing in improved and quality seeds more than quadrupled the yield of potatoes and was very rewarding. In other words, addressing the problem of seed quality in the potato cropping system resolved more than half the challenges of low yields. The other factor that explained the increased adoption of bylaws on seed quality was the practice of motivating farmers to adopt commercial farming.

The design of the study used myriad of arguments and methods to support the underlying qualitative foundation of it. Furthermore, the diverse arguments, theories, and methods aimed at addressing issues of rigor, by strengthening both internal and external validity of the study. Future studies may need conduct survey-based studies on the same topic to qualify the qualitative-based approach of this study

6. Conclusions

The bylaws (informal and formal) were rudimentary and scattered, appearing as best practices rather than a reference manual, and most of them had evolved away from informal (unwritten) to formal (written) phase, with the formal and predominant in influencing farmers' actions to intensify potato crop production. Despite their unique characteristics, they both supported the intensification of potato crop production in SWU.

The role of the institutional framework for implementing bylaws was most influential, though the individual-based value system came quite close in influencing SCI. Both fell under the category of the private sector, though the institutional ethic was most relevant in sustainable potato crop intensification because it covered both breadth and intensity in supporting SCI. Efficacy was the greatest challenge due to the parallel functioning of actors and weak coordination of the overall activities towards sustainable potato crop intensification in SWU.

The effects of bylaws on SCI were both direct (on primary makers of the bylaws) and indirect (on individuals and institutions who adopt them) to guide response towards SCI. The effect of informal and formal bylaws on sustainable crop intensification was limited, despite the noble role they played in supporting SCI, because of the limited focus soil and water conservation, quality of seed potato, and environmental sustainability in favour of consumption The emphasis was on improved and quality seed and storage facilities, which too failed to guarantee expected standards towards stronger SCI in SWU.

Recommendations

1. There is need to strength bylaws on soil and water conservation, improved and quality, seed and environmental sustainability to support SCI, which provide the basis of greater markets and sustainable livelihoods.

2. There is a need for a proper and distinct manual on bylaws for standardization, regionalization, and nationalization purposes to best influence farmers towards SCI.
3. There is a need to develop strong institutional, management structures, and coordination structures among the various actors that address institutional and management or implementation challenges of bylaws to support SCI.
4. There is a need for the most influential role of government and development partners in the intensification of potato crop production in SWU so that the relentless efforts of farmers' groups can be strengthened, and the confidence of individual farmers to join farmers' associations be improved.

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Hay Nutritional Quality and Grassland Bird Nesting: Impact of Delaying First Hay Cut on Dairy and Beef Production in Ontario

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Abstract

Perennial forage production exists in Ontario to support the livestock industry, but also provides nesting habitat for grassland birds such as the threatened Bobolink (*Dolichonyx oryzivorus*) and Eastern Meadowlark (*Sturnella magna*). Delaying hay harvest until July 15 or later allows most nestling birds to leave the nest, but the nutritional value of hay decreases substantially. This project estimated the nutritional and economic impact of delaying the first hay cut until after July 15 on beef and dairy production in Ontario, Canada. Forage crops were sampled across Ontario, analysis of nutritional value performed, and effects on production and economics modelled. 634 samples were collected over 13 weeks at 16 sites from May 21 to August 14 during 2014 and 2015. As expected, nutritional quality declined over the season. Crude protein decreased by 5.2%, total digestible nutrients by 7.7%, neutral detergent fibre digestibility (NDFd48) by 20.1%, while lignin increased by 3.5%, neutral detergent fibre by 13.1%, and acid detergent fibre by 9.9%. Estimated yearly milk production decreased 10.9 kg or C$7.87/dairy cow for each day of delay in harvest (2017 values). Estimated growth of backgrounding beef steers decreased 1.56 kg or C$5.49/head for each day of delay in harvest. This translated into lost revenue per acre for backgrounding steers of C$31 per acre and C$45 per acre for over wintering beef cows for a delay from mid-June to mid-July. Some agri-environmental incentives in Canada, US and Europe offset the reduced revenue due to lower quality forages. This analysis informs farmers about the cost of practices to benefit grassland birds and provides empirical data on how to structure stewardship incentives for these practices.

Keywords: forage, hay, pasture, ruminant nutrition, grassland birds, bobolink, *Dolichonyx oryzivorus*, eastern meadowlark, *Sturnella magna*

1. Introduction

1.1 The Dilemma of Forage Production Economics and Grassland Bird Conservation

Perennial forage production, both hay and pasture, is an important agricultural industry estimated in value at C$650 million in Ontario of a total C$5.1 billion in Canada in 2012 and supports livestock agriculture, including beef, dairy, sheep, horse, and other sectors (Brookfield, 2016; Yungblut, 2012; Fisher, 2008). In 2016, perennial forages, hay and pasture, were grown on over 20,000 farms and covering 1.2 million hectares of farmland in Ontario and 25.1 million hectares in Canada in 2016 (Statistics Canada, 2017). During the 20th and early 21st centuries, for various reasons, Ontario agriculture shifted to greater focus on annual crops. Hay and pasture area has declined dramatically (Smith, 2018, 2015), as it has across North America (Stanton et al., 2018), and many developed countries in recent decades (OECD, 2019).

Grassland birds, such as the Bobolink (*Dolichonyx oryzivorus*) and Eastern Meadowlark (*Sturnella magna*), commonly nest in tame pasture and hay production fields in many parts of Ontario (Ethier, Koper & Nudds, 2017; McCracken et al., 2013), while occupying native prairie and rangeland in other parts of North America

(North American Bird Conservation Initiative Canada, 2019; Renfrew et al., 2019; Wilsey, et al., 2019). In pre-European colonization conditions in Ontario, grassland birds were restricted to natural grasslands, wet meadows and habitats created by Indigenous peoples' landscape management (McCracken et al., 2013). Populations of grassland birds increased in Ontario with European-style agriculture during the 18th and 19th centuries, especially large areas of pasture and hay to support horses and ruminants (Smith, 2018, 2015; McCracken et al., 2013). Today the nesting of many grassland-nesting species depends on the shrinking area of pasture and hay on working agricultural lands with its concomitant grazing and harvesting, east of the extensive prairie ecosystems (Renfrew et al., 2019).

To improve understanding of trade-offs between forage nutritional quality, economics and grassland bird nesting success, this study quantified the change in the nutritional quality of Ontario forages over the growing season from mid-May to mid-August and modeled the nutritional, production and economic impacts of delaying hay harvest.

1.2 Bird Species Conservation Status

Bobolink and Eastern Meadowlark were designated threatened species in 2010 and 2012 respectively under Ontario's *Endangered Species Act* and in 2010 and 2011 under Canada's federal *Species at Risk Act* due to their declining populations (Smith, 2018; McCracken et al., 2013). Better understanding of the economic impact of practices to benefit grassland birds was identified as a research priority in the recovery strategy for these species (Ontario Ministry of Environment, Conservation and Parks, 2020; McCracken et al., 2013). This paper helps address that research priority. It also builds on previous analysis of the economic impact (Mussell et al., 2013) and some nutritional analyses included in grassland bird ecology studies (Diemera & Nocera, 2016; Brown & Nocera, 2017).

The specific causes of declining grassland bird populations are complex but failure of young birds to survive and reproduce is clearly a major concern (North American Bird Conservation Initiative Canada, 2019; Renfrew et al. 2019; Wilsey et al., 2019; Stanton, Morrissey, & Clark, 2018; Ethier et al., 2017; Ethier & Nudds, 2015; Hill et al., 2014; McCracken et al., 2013). Young birds depend on their parents for food for a long period and are especially vulnerable until they fledge. Hay harvest or grazing before the young birds fledge can result in bird mortality. Biologists estimate most young Bobolinks leave the nest in Ontario by July 15 in most years (Put et al., 2020; Campomizzi et al., 2019; Pintaric, 2018; Brown and Nocera, 2017; Diemer and Nocera, 2016). July 15 is quite late from a forage nutritional quality perspective (Diemera and Nocera, 2016; Mussell et al., 2013; Berdahl, Karn, & Hendrickson, 2004; Ball et al., 2001). In addition, if harvest only began after July 15, the overall first cut harvest period would extend well into August.

1.3 Forage Production

The science of forage production has long established the decline of nutritional value of forages through the growing season and sought to identify optimal harvest times (Moore, Lenssen, & Fales, 2020; Karn et al., 2004; Ball et al., 2001; Upfold and Wright, 1994). As perennial forages (hay) mature over the season there is a natural, inevitable drop in quality. Mature forages contain a higher ratio of stems to leaves, lower levels of available protein and non-structural carbohydrates, and higher amounts of fibre, providing limited energy and lower digestibility in both grasses and legumes (Foster et al., 2021; Jensen et al., 2017; Palmonari et al., 2014; Yari et al., 2012; Berdahl, Karn, & Hendrickson, 2004).

The species composition of perennial forage crops is variable but generally includes legumes and grasses in differing mixtures tailored to site conditions and livestock species (Ontario Ministry of Agriculture, Food and Rural Affairs, 2009; Upfold & Wright, 1994). Forage grown for dairy production tends to be primarily alfalfa-dominated (*Medicago sativa* L.; Roche et al., 2017), while forage for beef, sheep and other livestock species may have more grass species and include other legumes. Bobolink and Eastern Meadowlark are more numerous in grass-dominated hay fields but do nest in all types of hay (McCracken et al., 2013). As well, alfalfa-dominated hay grown for dairy production is usually harvested much earlier and more often than grass-dominated hay, to meet the higher nutritional needs. This combination of factors has led to some grassland bird conservation efforts to focus on mixed forage crops grown for beef, sheep, and other livestock, rather than alfalfa-dominated forage grown for dairy production (Diemera & Nocera, 2016; McCracken et al., 2013).

1.4 Conservation Measures

The trade-offs between conservation of grassland bird nesting and forage nutritional value for livestock and farm economics are becoming familiar. In Europe, many farmland, grassland, and meadow bird species also depend on agricultural grasslands and delaying forage harvest is often recommended (OECD, 2019; Broyer et al., 2016).

Stewardship funding and extension programs seek to address these trade-offs. Educational materials and tools allow farmers to assess those trade-offs and make informed decisions (e.g., Kyle & Reid, 2015).

Some agri-environmental incentive programs in Europe, United States, and Canada offer incentives to offset the reduced revenue due to lower quality forages (OECD, 2019; Smith, 2018; Perlut et al., 2011). Several US Farm Bill programs offer incentives, such as the US Conservation Reserve Program that funds setting aside land until after the nesting period (Shew et al., 2021). In Vermont, the Wildlife Habitat Incentive Program provided reimbursement of up to US$62/ha (C$33 / acre) for delayed hay cutting in 2008–2009 (Perlut et al., 2011). An ecological services valuation approach was also tried in the US, raising funds from the public for on-farm Bobolink conservation (Swallow et al., 2018).

Europe has a long history with conserving farmland birds and plant and animal species on farmland and semi-natural habitats and has well-funded agri-environmental schemes focused on biodiversity (OECD, 2019). So European agri-environmental schemes offer significant incentives for biodiversity conservation including farmland, grassland, and meadow birds (e.g., as much as £260 /ha, or C$183 / acre for the endangered Corn Crake; Perkins et al., 2011).

In Ontario, the Species at Risk Partnerships on Agricultural Lands program and the Grassland Stewardship Program provided up to C$40/ac/year for delayed haying (Johnson, 2020; Ontario Soil and Crop Improvement Association, 2022, 2018). A PEI program offered farmers C$25 / acre for delayed haying to benefit grassland birds (Johnson, 2020).

1.5 Study Purpose

This study quantified the change in nutritional quality of Ontario forages over the growing season from mid-May to mid-August and estimated the production and economic effects in beef and dairy production systems. This is to improve understanding of the trade-offs between forage nutritional quality, economics, and grassland bird nesting success. Estimates of the reduced quality of forage allow the calculation of reduced animal weight gain or milk production, and from that the estimation of economic impact based on costs and prices. These in turn allow for calculation of reduced economic value of hay on a per acre basis based on average hay yields. These estimates inform evidence-based educational materials and stewardship programs that assist farmers in decision-making regarding practices to benefit grassland birds.

2. Methods

2.1 Field Sampling and Locations

Perennial forage (hay) samples were collected weekly at 16 cooperating farm sites across Ontario from May 21 - August 14 of 2014 and 2015 (Table 1 and Figure 1; two sites were sampled only in 2014), (for detail see Wells et al. 2018). This extends beyond the usual first-cut hay harvest dates to mid-August to reflect an extended season under hypothetical delayed start of hay harvest until July 15, with hay harvest continuing until complete.

On cooperating farms, a section of each field was cordoned off and left unharvested and undisturbed for sampling throughout the duration of the project. Samples were taken from a 45.7x45.7 cm (18x18 inch) plot by cutting the forage 7.6 cm (three inches) above the ground. One or two samples were taken each week for 12-13 weeks. 634 forage samples were collected for analysis, 292 in 2014 and 342 in 2015. Collected samples were weighed, bagged and frozen until delivered to the lab for analysis.

Figure 1 shows the geographic locations of the 16 sampling sites as well as the area of hay by township in Ontario (2011 census). The sampling sites were selected to reflect the differences in growing conditions across the province and predominant areas of forage production. The sites reflect a wide range of values of Crop Heat Units for production from 2400-3100 (Table 1), covering most common growing conditions for forages. The sites include different species mixes (Table 1): legume (alfalfa-dominated), grass (grass-dominated) or mixed (a relatively equal mixture of legumes and grasses). Where possible, sites with all three types of forage categories were sampled in each geographic region. The sampling sites were grouped into four regions and location data are noted in Table 1 and used in nutritional modeling. The two northern Ontario sites are excluded from regional comparisons due to small sample size for the northern region.

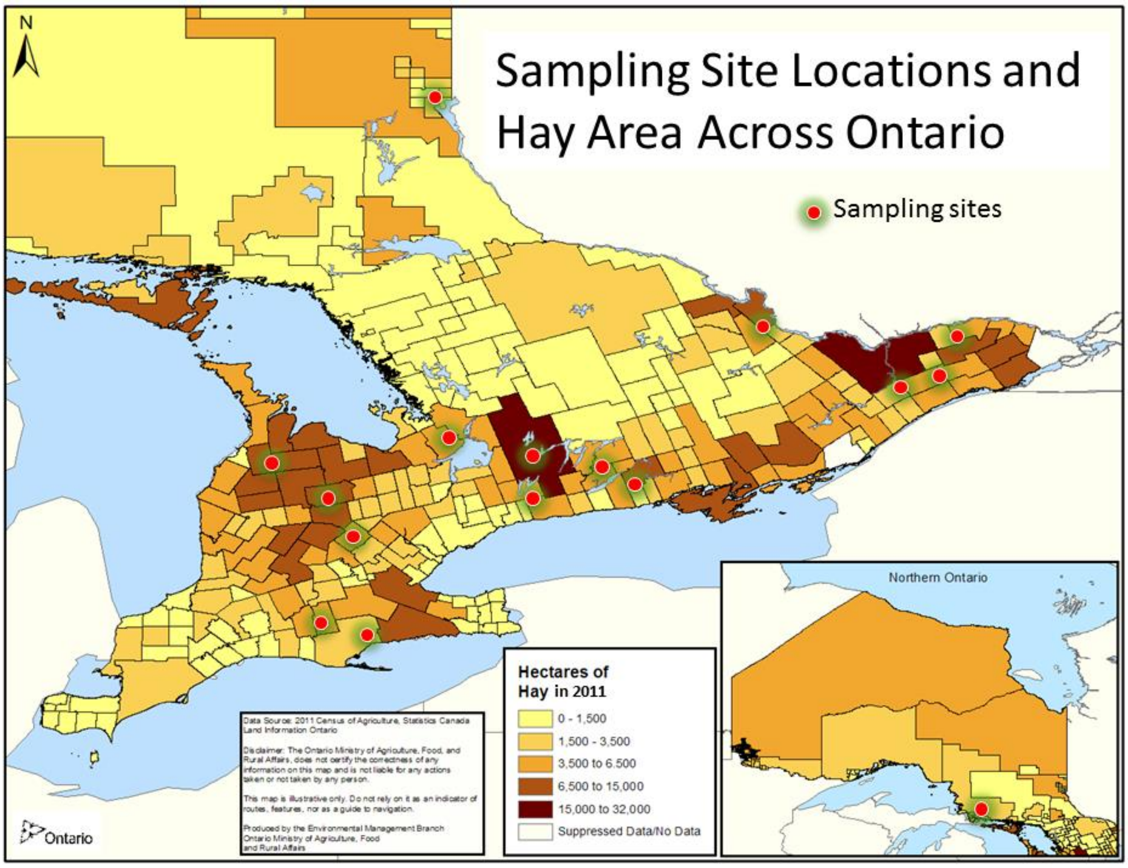

Figure 1. Sampling site locations and hay area across Ontario

Table 1. Location and characteristics of sampling sites for delayed harvest forage nutritional study

Region	County, Region, District	Sampling Site Location	Crop Heat Units	Type of Forage
Southwestern Ontario	Norfolk County	St. Williams	3100	Grass-dominated
	Oxford County	Embro	2900	Legume-dominated
	Bruce County	Chesley	2700	Grass-dominated
	Wellington County	Elora	2700	Legume-dominated
	Grey County	Dundalk	2500	Grass-dominated
Southeastern Ontario	Prescott and Russell	Alfred	2900	Mixed
	Leeds and Grenville	Kemptville	2900	Grass-dominated
	Stormont, Dundas and Glengarry	Winchester	2900	Legume-dominated
	Renfrew	Renfrew	2700	Grass-dominated
Southcentral Ontario	Kawartha Lakes (formerly Victoria)	Cambray	2700	Grass-dominated
	Durham Region	Enniskillen	2900	Legume-dominated
	Peterborough County	Keene	2700	Grass-dominated
	Northumberland County	Warkworth	2900	Mixed
	Simcoe County	Oro	2700	Grass-dominated
Northern Ontario	Algoma District	Echo Bay	2500	Grass-dominated
	Timiskaming District	New Liskeard	2400	Grass-dominated

2.2 Laboratory Analysis

Forage samples were analyzed at a commercial feed laboratory (A&L Canada Laboratories Ltd., London, Ontario). This is the first systematic survey over time (season and year) of forage quality in Ontario that analyzed samples for neutral detergent fibre digestibility (NDFd48), a forage analysis method that assesses NDF digestibility using an in vitro system that approximates the true digestibility in the rumen. Samples were analyzed for NDFd using the Daisy II incubator (Ankom Technology, Macedon, New York) using the Van Soest buffers for macro and micro solutions. In vitro true digestibility was determined using Ankom Technology Method 3. After the required in vitro incubation time, NDF was determined using Ankom Method 6, Neutral Detergent Fibre in Feeds – FBT for A2 fibre analyzer.

Laboratory analyses were performed on each sample (634 samples) to determine the concentration of dry matter (DM), neutral detergent fibre (NDF), acid detergent fibre (ADF), crude protein (CP), soluble protein, undegradable intake protein (UIP), lignin, and other variables such as micronutrients. Neutral Detergent Fibre Digestibility (NDFd48) was also measured to assess digestibility in rumen fluid (for 48 hours, see more below). Key variables are defined, and their significance described below (Weiss & Hall, 2020; Ontario Ministry of Agriculture, Food and Rural Affairs, 2016; Ball et al., 2001).

Dry Matter - is the moisture-free material left after drying the sample in a laboratory oven. It is standard practice to evaluate the feed and balance rations using a dry matter basis.

Crude Protein (CP) - is calculated based on the nitrogen content of the feed. Protein is approximately 16% nitrogen and total nitrogen is measured to calculate a value for crude protein. CP is expressed as a percent of dry matter.

Soluble Crude Protein - is most readily available to animals and can be absorbed across the rumen wall. Soluble protein is expressed as a percentage of total crude protein.

Undegradable Intake Protein (UIP) – or by-pass protein, is the fraction of protein that is resistant to degradation by rumen microbes. UIP is expressed as a percentage of total crude protein.

Acid Detergent Fibre (ADF) - refers to the cell wall portion of forage, made up of lignin and cellulose. The value reflects the ability of animals to digest the forage. ADF represents the portion of hay that doesn't dissolve in an acid detergent solution. It has a strong (negative) relationship with total forage digestibility. ADF is used to define guidelines for hay quality, as ADF increases, forage quality declines. ADF is expressed as a percent of dry matter.

Neutral Detergent Fibre (NDF) - refers to the cell wall fraction that includes ADF and hemicellulose. The NDF value is related to the amount of forage the animal can consume and as NDF increases, the dry matter intake generally decreases. NDF is expressed as a percent of dry matter.

Neutral Detergent Fibre Digestibility (NDFd) – is feed digestibility in rumen fluid based on 48 hours (NDFd48) in an in-vitro digestibility analysis. It measures how much of the feed has been digested by the microbes in rumen fluid after 48 hours. NDFd48 is expressed as a percent of NDF.

Total Digestible Nutrients (TDN) - an equation is used to calculate energy or total digestible nutrients (TDN). This is the first limiting parameter for milk production. This measure includes NDF, lignin, fat, starch, mineral and bound protein and is used to estimate energy values. TDN is expressed as a percent of dry matter.

Lignin - is the indigestible portion of the plant cell and increases with the maturity of the forage. Lignin negatively affects the digestion of the cell wall by acting as a physical barrier to the microbial enzymes. Lignin is expressed as a percent of dry matter.

Statistical analysis of the laboratory nutritional analysis data was undertaken using Microsoft Excel and associated statistical add-ins and PSPP statistical analysis software version 1.4.1. Analytical tools include analysis of variance, regression, and correlation.

2.3 Nutritional Modeling and Economic Analysis Methods

Modeling methods were used to estimate the effects on milk production and weight gain in livestock fed rations including forages harvested on different dates. The standard National Research Council models for livestock production were used for estimates for dairy (National Research Council, 2001) and beef production (National Academies of Sciences, Engineering, and Medicine, 2016). These models are sets of equations developed by industry experts to predict production outcomes of animals fed varying diets, based on decades of research and are viewed as industry and academic standards.

For the nutritional modeling study, provincial level results included all sites and samples. Regional estimates were made based on the sites grouped into the four regions (Table 1) and the nutritional data was averaged to provide a single value for each sampling week for each region. Region-specific results for northern region sites are not presented here due to the small sample size, but the northern sites' data are included in provincial level estimates.

The modelling required inputs regarding composition of feed rations, weight gain, milk production, hay yield, prices, costs, and other factors for each scenario. These are outlined with the results for each scenario.

3. Results

3.1 Forage Sampling

Table 2 shows the average value, percent change and correlation with date of first cut May to August for eight key nutritional parameters. Most variables associated with positive nutritional value decline significantly through the season including Crude Protein (CP), Neutral Detergent Fibre Digestibility (NDFd48) and Total Digestible Nutrients (TDN). Soluble Crude Protein and Undegradable Intake Protein (UIP) changed relatively little. Variables indicative of low digestibility increased over the season, Lignin, Acid Detergent Fibre (ADF) and Neutral Detergent Fibre (NDF). Again, these results are typical and reflect well known trends in seasonal forage quality (e.g., Berdahl et al., 2004; Ball et al., 2001; Upfold & Wright, 1994).

Table 2. Change in nutritional parameters of forage first harvested from May to August and correlation with date, averaged for all sites

Variable	Mean 2014-2015 (percent of dry matter)[1]	2014 Mean percent change May-Aug	2015 Mean percent change May-Aug	Overall Mean May-Aug change with standard error	Correlation with Date of first cut[2]
Crude Protein (CP)	12.91	-4.5%	-5.9%	-5.2% ±1.3	-0.869***
Soluble Crude Protein	43.64	-0.7%	-1.4%	-1.1% ±2.1	-0.217
Un-degradable Intake Protein (UIP)	28.18	0.4%	0.7%	0.5% ±1.0	0.218
Neutral Detergent Fibre Digestibility (NDFd48)	45.10	-13.0%	-27.3%	-20.1% ±5.4	-0.942***
Total Digestible Nutrients (TDN)	61.60	-5.8%	-9.7%	-7.7% ±1.2	-0.970****
Lignin	5.61	+2.2%	+4.8%	+3.5% ±0.8	0.991****
Acid Detergent Fibre (ADF)	35.05	+7.5%	+12.4%	+9.9% ±1.6	0.970****
Neutral Detergent Fibre (NDF)	52.32	+9.4%	+13.1%	+11.2% ±2.1	0.952****

[1] *Quantities are percent of dry matter except for soluble protein and undegradable intake protein (UIP) which are expressed as percent of crude protein and Neutral Detergent Fibre Digestibility (NDFd48) which is expressed as percent of NDF.*

[2] *Statistical significance of correlation using two-tailed t-test test: * = P ≤ .05; ** = P ≤ .01; *** = P≤ .001; **** = P ≤ .0001.*

The values of all variables were significantly different among sites (ANOVA, F-test, p<0.001). Some variables varied significantly between the regions identified in Table 1 (CP, ADF, NDF, NDFd48, TDN, Lignin; ANOVA, F-test, p<0.05 or more significant). Many of the nutritional variables showed a statistically significant influence from crop heat units (CP, ADF, NDFd48, TDN, soluble protein, UIP, Lignin) while controlling for seasonal change as a covariate (ANOVA with covariate, F-test, p<0.001). Forage species mixture type also significantly influenced some nutritional variables (CP, NDF, NDFd48, Soluble Protein, UIP, Lignin, ANOVA, F-test, p<0.05 or more significant). Such results are expected.

3.2 Nutrition Modeling

The nutrition modeling uses the lab analysis of forage samples as inputs into standard nutrition models to estimate the effect of decreasing nutritional quality over the season on milk production and weight gain. Modeling included analyses for: dairy cows, beef steers and beef cows. Results for each of these are presented below.

3.2.1 Nutrition Modeling Results: Dairy

Most lactating dairy cows in Ontario are fed a total mixed ration (TMR) containing some combination of corn silage, concentrated energy, protein and vitamin/mineral supplements, and forages, usually in the form of an alfalfa silage (haylage). The 2001 NRC dairy equations were used to generate estimates of how feeding forages harvested at each timepoint during the summer would affect milk production.

The following assumptions were made when using the dairy software:

- Mature cows with a body weight of 681 kg
- The average milk yield is 36 kg/day
- The cows are 105 Days in Milk

The following diet (on a dry matter basis), which is representative of a typical Ontario ration, was used for all calculations, with the quality of all ingredients, other than hay, being constant:

- 3.6% straw
- **25.5% of the sampled hay**
- 38% corn silage, containing 40% grain
- 19.4% high moisture corn
- 13.5% custom concentrate

Estimated milk production (as measured by net energy or NE allowable milk and metabolizable protein or MP allowable milk), and protein intake (CP crude protein, MPI metabolizable protein intake) all decreased over the season, declining with the decreasing quality of forage already noted (Table 3).

The decline in estimated milk production (Table 3) using forage harvested later shows the impact of the maturity of forage samples on milk production. Milk production is determined by dietary energy and protein availability. Energy is utilized by microbes in the cow's rumen which ferment the carbohydrates into volatile fatty acids (VFAs) utilized by the cow as energy and to synthesize lactose and fatty acids.

Dietary protein is found in two forms: rumen degradable protein (RDP) and undegradable protein (UIP). The rumen microbes utilize the RDP to synthesize their microbial proteins that flow out of the rumen and are digested in the cow's small intestine. UIP is unavailable to the rumen microbes, but can be available to the cow, if the protein can be digested by the cow's own enzymes, which is dependent on the protein being unbound from fibre. Neutral detergent (hemicellulose) bound crude protein may be freed by the rumen microbes, but is unavailable once past the rumen, acid detergent (cellulose + lignin) bound protein is completely unavailable and will pass through undigested.

Table 3. Change in dairy cows' estimated milk production and protein intake on a diet including forage first cut May-August 2015

	Mean value	Percent change over season	Correlation with date of first cut[1]	R^2
Net energy allowable milk (kg/day)	35.5	-4.21	-0.966****	93.3%
Metabolizable protein allowable milk (kg/day)	36.0	-8.32	-0.827***	68.3%
Crude protein intake kg/d	3.7	-9.34	-0.828***	68.5%
Metabolizable protein intake g/d	2551.0	-4.68	-0.824***	67.9%

[1] Statistical significance of two-tailed t-test test reported: * = P ≤ .05; ** = P ≤ .01; *** = P≤ .001; **** = P ≤ .0001.

The amount and availability of protein is important as it determines how much protein is available to support lactation. Net energy and metabolizable protein are both critical to supporting milk production and a decrease in either will cause a loss in milk production.

Both crude protein and metabolizable protein intake (MPI) decline in hay harvested May-August (Table 3). The trend in MPI shows the effect of the maturing sampled forages on protein intakes and retention. MPI indicates the level of crude protein in the diet and how available the protein is to the animal.

These trends are expected as mature forages contain a greater ratio of stems to leaves. The leaves drive forage value with high levels of available protein and non-structural carbohydrates, providing energy. Stems are composed of primarily fibre as NDF and ADF, providing limited energy and much of the protein is fibre-bound.

As forage is left to mature, more volume of forage accumulates, but mostly from stem growth, increasing NDF and ADF and diluting available energy and protein.

3.2.2 Nutrition Modeling Results: Beef Steers

For the analysis for beef steers, feed information was input into the feed library of the Beef Cattle Nutrient Requirements Model 2016 (National Academies of Sciences, Engineering, and Medicine, 2016). The following assumptions were made for all calculations:

- Diet fed to Angus steers on a backgrounding program
- Initial body weight of 226 kg (500lb) and finishing at 408 kg (900lb)
- Steers were fed a 100%-forage diet, consisting of the sampled forage
- Steers would be fed *ad libitum,* therefore the input dry matter intake (DMI) was matched to the predicted DMI

Beef steer weight gain decreased over the season with decreasing forage quality as illustrated in Table 4. The measures of weight gain are metabolizable energy (ME) allowable gain and metabolizable protein (MP) allowable gain. ME and MP allowable gain follow the same principles as NE and MP allowable milk for dairy cows, but for backgrounding beef steers the energy and protein are being utilized to support structural growth of muscle tissue.

Table 4. Trends in beef steer estimated weight gain on a diet of forages harvested May-August 2015

	Mean value	Percent Change over season	Correlation with date of first cut[1]	R^2
Metabolizable Energy allowable gain (kg/day)	0.762	-58.8%	-0.984****	96.8%
Metabolizable protein allowable gain (kg/day)	0.726	-35.9%	-0.945****	89.3%
Expected Dry Matter Intake (kg/day)	7.4	0.63%	0.648*	41.9%

[1] Statistical significance of two-tailed t-test test: * = $P \leq .05$; ** = $P \leq .01$; *** = $P \leq .001$; **** = $P \leq .0001$.

The primary production parameter for beef cattle is daily body weight gain and it tended to decrease, similarly to the predicted milk production for dairy cattle, as the rations included forage from lower quality later harvests. These results are due to the increase in the proportion of stems in the mature forage, causing an increase in fibre and decrease in the concentration of energy and protein. While dry matter intake increased some, the steers cannot eat enough to compensate for the lower nutrient concentration, resulting in lost production.

3.2.3 Nutrition Modeling Results: Wintering Beef Cows

For the analysis for feeding wintering beef cows, forage feed information was input into the feed library of the Beef Cattle Nutrient Requirements Model 2016 (National Academies of Sciences, Engineering, and Medicine, 2016). The following assumptions were made for all calculations:

- Diet is being fed to 3-year-old Angus cows being over-wintered
- Cows have a mature weight of 532 kg (1170lb)
- Cows are 200 days pregnant and give birth to a 40 kg calf in April, therefore non-lactating
- Average outdoor temperature is -5 C, with average lows of -10 C and wind speeds of 15 km/h. The cows are assumed to be sheltered.
- Cows are fed harvested forage from October to April (180 days)
- Cows are fed enough of sampled forage to exceed energy requirements by 0.5 Mcal/day

This model scenario differs from the others in that DMI is allowed to increase to exceed the daily energy requirements noted above. The DMI is also required to slightly exceed energy requirements, which represents the primary cost of keeping a mature beef cow over the winter. With a drop in feed quality, cows need to eat more to meet their nutrient requirements. This is reflected in the increase in DMI using forage harvested later in the period May-August (Table 5). Linked to the increased DMI for late season forage, both metabolizable energy (ME) and metabolizable protein (MP) also increase with the later season forage. Days to gain one body condition score are included to demonstrate that the cows are being fed just enough to slightly exceed requirements, as a cow fed to her maximum intake could gain one body condition score (BCS) every 30 days (Table 5). Increases in forage maturity resulted in a need for higher feed intakes to meet the cow’s nutritional requirements.

Table 5. Wintering Beef Cows: Trends in dry matter intake, weight gain, energy, and protein on a diet of forage harvested May-August 2015

	Average	Percent change over season	Correlation with date of first cut[1]	R^2
Dry Matter Intake (kg/d)	7.52	+25.0%	0.978****	95.7%
Metabolizable Energy provided (Mcal/d)	16.82	+7.1%	0.975****	95.0%
Metabolizable Protein provided (g/d)	508.9	+9.3%	0.955****	91.2%
Days to gain one Body Condition Score	298.73	-1.6%	-0.492	24.2%

[1] Statistical significance of two-tailed t-test test: * = P ≤ .05; ** = P ≤ .01; *** = P≤ .001;
**** = P ≤ .0001.

3.3 Results: Production Loss and Economics

Based on the documented decreases in nutritional value of forages, milk output, and weight gain, all showed linear declines over the season. To determine the opportunity cost of lost production due to delaying harvest by an additional day, linear regression models predicting production loss per day of delayed harvest were calculated from the relationships illustrated in Table 3 and Table 5. The models were then adjusted to an annual scale to be more relevant and simpler to interpret. Predictions of the lost revenue per animal per unit time were made by multiplying the production models with market prices.

3.3.1 Dairy and Beef

Predicted milk yields from diets containing the sampled forages declined over the season (Table 3 and Table 5). The economic value of lost milk production due to time of harvest was estimated based on March 2017 sale prices of milk components of C$10.71/kg fat, C$7.45/kg protein and C$1.52/kg other solids, assuming 3.8% fat, 3.1% protein and 5.5% other solids in the predicted milk yields (Dairy Farmers of Ontario website, March 2017). For each day of delayed harvest, annual revenue from milk sales was predicted to decline C$7.87/cow provincially, or C$4.65/cow, C$5.16/cow, and C$7.41/cow for Southcentral, Southeastern, and Southwestern Ontario, respectively (Table 6).

For an average 80-cow dairy farm in Ontario, the revenue loss is expected to be C$630 for each additional day of delay, which is equivalent to C$19,000 for 30 days of delay and C$38,000 for 60 days of delay. 30 days would represent a delay from mid-June, generally an optimal time for harvest nutritionally, to mid-July, optimal for the fledging of nestling birds. First cut in forage for dairy is often in mid to late May, closer to a 60-day difference between mid-May and mid-July.

The economic value of lost bodyweight gain in beef cattle was estimated based on an average April 2017 auction price of C$3.52/kg live weight and a backgrounding duration of 400 d. For each day of extending the harvest, reduced weight gain was equivalent to C$5.49/head provincially, or C$6.96/head, C$6.36/head, and C$4.11/head for Southcentral, Southeastern and Southwestern Ontario, respectively (Table 6).

For an average 175-head feedlot in Ontario, the revenue loss is expected to be C$961 for each additional day of delay, which is equivalent to C$28,830 for 30 days of delay. First cut timing for hay for beef is variable but is often mid-June to early-July.

Table 6. Average change in annual dairy and beef cattle performance per day of delayed harvest across Ontario and in each region

	Province-wide Ontario	Southwest	Southcentral	Southeast
Milk production change (kg/yr/cow)	-10.9	-10.27	-6.44	-7.15
Value of milk production change (2017 C$/yr/cow)	-C$7.87	-C$7.41	-C$4.65	-C$5.16
Beef bodyweight gain (g/d/head)	-1.56	-1.16	-1.97	-1.79
Value of beef bodyweight gain (2017 C$/400 d/head)	-C$5.49	-C$4.11	-C$6.96	-C$6.36

3.4 Results: Impact on Cost of Production and Economics

Another method to analyze the cost of delaying forage harvest is to compare production costs, in this case feed costs, using forage harvested on different dates. The outputs must be for the entire season, so the cost of inputs may be fairly compared. By estimating the cost of the different forages and using the predicted feed intakes, the production cost of raising an animal through its phases can be estimated.

For beef cows and steers the following assumptions were used for yield calculations and costs:

- A blend of 75% timothy and 25% red clover was being fed
    - This assumption was used to estimate yield. This is reasonable for the sampled forages. All predictions for DM required per animal were calculated from the sampled forages.
- Cuts would be spaced 35 days apart but could be pushed to 30 days if needed.
- Critical fall harvest period for clover determined when another cut was no longer feasible. August 31st was used as the last day to cut for Southcentral, Southeastern and Southwestern Ontario.
- For simplicity, cuts 2 and 3 were considered of equal quality to the first cut. Few comparable estimates are available.
- Total estimated forage yield was calculated as the sum of yield from cuts 1, 2 and where possible cut 3. Total yield was estimated for each date of hypothetical first cut with second and third cuts 35 days after the previous cuts.
- Estimated yield (from Ontario Ministry of Agriculture, Food and Rural Affairs, 2016) for first cut were 1200 kg/ac in the last week of May rising to 2200 kg/ac in August. Estimated second cut yields were 650 kg/ac when the first cut occurred in late May dropping to 375 kg/ac when the first cut occurred in the last week of July and zero after that. Estimated third cut yields were 450 kg/ac when the first cut occurred in late May, dropping to 281 kg/ac when the first cut occurred in the third week of June and zero after that.
- Per acre costs were estimated using the 2017 edition of Ontario Ministry of Agriculture, Food, and Rural Affairs' Publication 60: Field Crop Budget for Alfalfa-Timothy Hay and the 2016 Farmland Value and Rental Value Survey (Deaton, 2017)
- Variable costs such as fuel, labour and custom work were adjusted based on the number of cuts undertaken
- Rent costs were C$75, C$115, and C$140/acre for Southcentral, Southeastern and Southwestern Ontario, respectively.

To determine the cost of delayed harvest, the production cost per acre of hay was estimated and average estimated yields were taken from Ontario Ministry of Agriculture, Food and Rural Affairs (2016). Then estimated production costs per acre were used to calculate the feed cost per kg of DM, using the following formulae.

$$Feed\ Cost = \frac{Cost/Acre}{kg\ DM/Acre}$$

Next, the amount of DM required per animal during their phase of production was calculated assuming they were fed solely on the sampled forage.

$$DM\ req.per\ Animal = DMI\ \left(\frac{kg}{d}\right) \times Days\ on\ Feed$$

Using the cost of the sampled forage (C$/kg of DM) and the DM requirements, the cost of feeding one steer or cow through their respective production phase was determined.

$$Cost\ per\ Animal = \frac{Feed\ Cost}{kg\ DM} \times \frac{DM\ req.}{Animal}$$

Finally, the following equation was used to determine the cost per acre of delayed harvest:

$$Cost/Animal_{mid-June} = Cost/Animal_{mid-July}$$

$$Cost/Animal_{mid-June} = DM\ req_{mid-July} \times \frac{Subsidized\ Cost/Acre_{mid-July}}{kg\ DM/Acre_{mid-July}}$$

$$Subsidized\ Cost/acre_{mid-July} = \frac{Cost/Animal_{mid-June}}{DM\ req./Animal_{mid-July}} \times kg\ DM/Acre_{mid-July}$$

$$Loss\ of\ Delayed\ Harvest = Original\ Cost\ per\ Acre - Subsidized\ Cost\ per\ Acre$$

$\text{Cost/Animal}_{\text{mid-June}}$, DM $\text{requirement}_{\text{mid-July}}$ and kg of $\text{DM/Acre}_{\text{mid-July}}$ were calculated. Subsidized $\text{Cost/Acre}_{\text{mid-July}}$ was the calculated cost of production, of a first cut taken in mid-July that would need to be met to match the cost per animal of a 1st cut taken in mid-June.

3.4.1 Backgrounding Steers

For backgrounding steers, a target rate of an Average Daily Gain (ADG) of 0.6kg/d was selected for the models as it was predicted that forages sampled in both mid-June and mid-July could both meet this target, with the only variable being the intake required to meet the target. This allowed for the cost of delayed harvest to be estimated on a per acre basis as it is assumed that other costs associated with raising a steer (housing, labour, etc.) would remain constant as the predicted time to finishing weight was the same for steers fed the mid-June and the mid-July first cuts.

Table 7 shows the average estimates of production impact per acre. Average dry matter intake (DMI) increases May-August to meet the average daily gain (ADG) target as forage quality decreases. As quality decreases, average days to finish, and average dry matter required all increase. As date of first cut increases, the likelihood of a second or third cut decreases, reducing cost per acre. As dry matter intake increases, average cost per steer increases.

Table 7. Estimate of mean production and economic impact and change over season for forage production, backgrounding steers and wintering beef cows on forage harvested May-August

	Mean	Percent change over season	Correlation with date of first cut[1]	R^2
Forage Production				
Dry Matter Intake (kg/d)	6.84	14.5%	0.968***	93.8%
Average Daily Gain (kg/d)	0.584	-11.4%	-0.822***	67.5%
Days to Finish	309.98	+13.8%	0.815***	66.4%
Dry Matter Required (kg)	2125.7	+28.8%	0.914***	83.6%
Cost/ acre	C$401.20	-19.6%	-0.804***	64.6%
Cost/ kg Dry Matter	C$0.1481	-5.7%	-0.324	10.5%
Backgrounding Beef Steers				
Cost/ beef steer	C$314.42	23.5%	0.656*	43.1%
Wintering Beef Cows				
Cost/ beef cow	C$200.36	20.2%	0.703**	49.4%

[1]Statistical significance of two-tailed t-test test: * = $P \leq .05$; ** = $P \leq .01$; *** = $P \leq .001$; **** = $P \leq .0001$.

Figure 2 shows the variation in production cost per animal for forage first cut on a certain date over the May to August season. This shows optimal harvest period in June and the cost increases when using late harvest forages to feed backgrounding beef steers and wintering beef cows.

On a per acre basis, the value lost from delaying 1st cut from mid June to mid July, when backgrounding steers was found to be approximately C$31 provincially, or C$42, C$36, and C$32 per acre (2017) for Southcentral, Southeastern and Southwestern Ontario respectively.

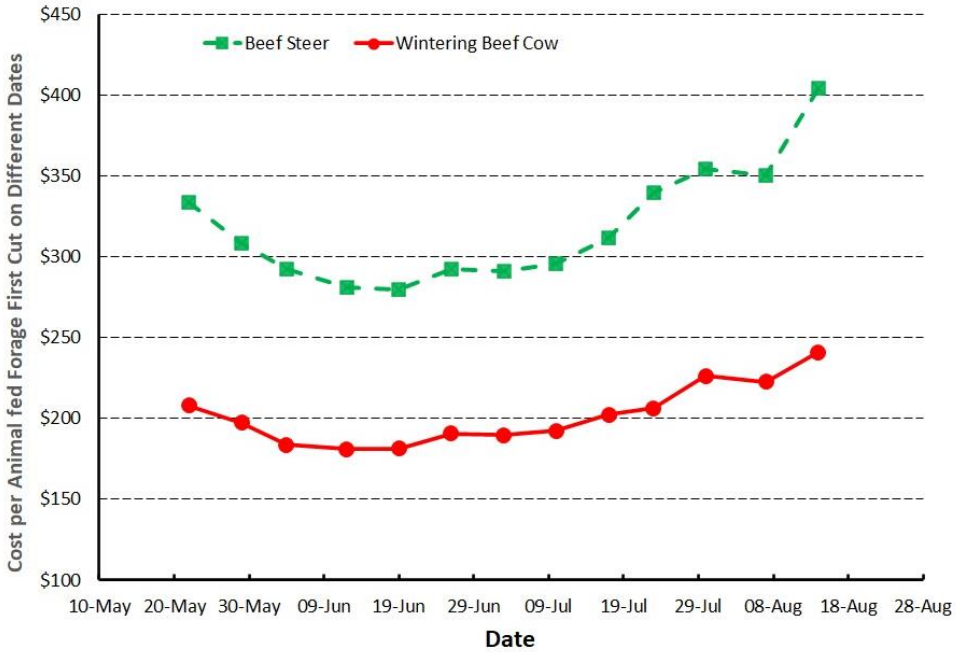

Figure 2. Estimated cost per animal (C$ 2017) for wintering beef cows and backgrounding beef steers fed rations including forage first cut on different dates May-August

3.4.2 Wintering Beef Cows

For wintering beef cows, the reported feed intakes are the same as those used in the previous section on beef cows (Section 3.2.3). Table 7 and Figure 2 present estimates of costs for wintering beef cows using hay first harvested at different stages in the season. Intake of dry matter would increase over the season as nutritional quality decreases. Average cost per cow increases due to the increased intake required to provide nutrition.

On a per acre basis, the value lost from delaying 1st cut from mid-June to mid-July, when feeding cows over winter, was found to be approximately C$45 provincially, or C$66, C$45, and C$46 per acre for Southcentral, Southeastern and Southwestern Ontario respectively (Table 8) reflecting regional differences (2017 values).

Table 8. Estimated cost per acre of reduced production value due to use of hay harvested mid-July compared to mid-June (C$ 2017)

	Provincial	Southwest	Southcentral	Southeast
Backgrounding steers	C$31/ acre	C$32 / acre	C$42/ acre	C$36/ acre
Wintering beef cows	C$45 / acre	C$46/ acre	C$66/ acre	C$45/ acre

4. Discussion

Hay crops and pasture exist to produce feed for livestock and the livelihoods of farmers. Yet their existence creates what biologists call surrogate or secondary nesting habitat for grassland bird species like the Bobolink and Eastern Meadowlark, suggesting multiple management objectives and potential trade-offs. Delayed hay harvest is often recommended by biologists to benefit the survival of grassland birds, like Bobolink and Eastern Meadowlark (Put et al., 2020; Campomizzi et al., 2019; Pintaric, 2018; Brown and Nocera, 2017; Diemer and Nocera, 2016), and also for European farmland birds (OECD, 2019; Broyer et al., 2016). The nutritional quality of perennial forages (hay) inevitably declines over the growing season (Moore et al., 2020; Karn et al., 2004; Ball et al., 2001; Upfold and Wright, 1994). The production and profitability of farms are necessarily affected by delayed hay cutting.

This study quantified the nutritional quality of forages across the entire season beyond typical harvest dates to assess the impact of delayed hay harvest on beef weight gain and dairy milk production. In a new contribution, using nutritional and economic modeling, yield, cost and price data, this study projected the economic impact of a delayed first cut on dairy and beef production per animal, per day of harvest delay, per acre, and for an average farm operation. This provides scientific evidence to inform incentive program design and educational materials for on-farm decision-making. It also contributes to a priority research topic identified in the recovery strategy for these threatened species (Ontario Ministry of Environment, Conservation and Parks, 2020; McCracken et al., 2013).

Timing of Bobolink fledging generally begins in mid-June and often peaks in late June or early July (Pintaric, 2018; Brown and Nocera, 2017; Diemera and Nocera, 2016), although there can be significant annual and geographic variation. There are also geographic differences in the seasonal change of nutritional quality, as revealed in this study and Brown and Nocera (2017). Delay of harvest until July 15 is thought to allow fledging of most nestlings (Put et al., 2020; Kyle and Reid, 2015). Delay until July 1 may allow 80-90% of young to fledge (Mussell et al., 2013). This study links knowledge of bird fledging and survival with nutritional value and economic impact and allows a detailed empirical basis for trade-offs and optimization between bird conservation and livestock production (also see Brown and Nocera, 2017).

Inter-disciplinary research on grassland bird BMPs would better integrate the assessment of their ecological efficacy with production, economics, and on-farm practicality. European researchers have done more interdisciplinary work including both conservation and agricultural researchers to assess different aspects of projects (e.g., Tallowin and Jefferson, 1999). Inter-disciplinary approaches should be considered for future projects in Canada, such as coupling forage analysis, nutritional modeling, economic analysis, and bird ecology and nesting studies.

The results of this study will support on-farm decision-making by farmers and landowners, providing science-based estimates of the economic and production impacts of delaying the first cut of hay until after July 15, commonly recommended to benefit grassland birds. For example, a farmer considering the suggested BMPs for delayed haying (Kyle and Reid, 2015), would be better able to assess the impact those practices would have on production and income. Combined with data on bird survival, this makes it easier to assess the economic impact of cutting one or more fields later to benefit bird nesting.

The findings will also ensure the design of stewardship programs can be based on scientific evidence. Considerable research has gone into evidence on bird survival and reproduction. The estimates of reduced production values in this study support the cost sharing values and approaches taken under the Species at Risk Partnerships on Agricultural Land program for delayed haying (Ontario Soil and Crop Improvement Association, 2018, 2022). So, the research supports both informed farm-level decision making by farmers and evidence-informed decisions in program and policy design.

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White Prairie Clover (Dalea candida Michx. ex Willd.) and Purple Prairie Clover (Dalea purpurea Vent.) in Binary Mixtures with Grass Species

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Abstract

Native forage legumes may have potential for summer/fall grazing in semiarid prairie regions in mixture with grasses. The objective of this study was to evaluate two native clovers in binary mixtures with the introduced grasses when harvested in July and September to simulate late summer or fall stockpile forage. Eight binary clover–grass mixtures were seeded in a split-plot design with 4 replications at Swift Current, Saskatchewan, Canada. Mixtures included (i) AC Antelope white prairie clover (WPC)-Admiral meadow bromegrass (MBG), (ii) WPC-AC Success hybrid bromegrass (HBG), (iii) WPC-Bozoisky Russian wildrye (RWR), (iv) WPC-TomRWR, (v) AC Lamour purple prairie clover (PPC)-AdmiralMBG, (vi) PPC-AC SuccessHBG, (vii) PPC-BozoiskyRWR, and (viii) PPC-TomRWR. Clover establishment differed (p = 0.03) in July where WPC had 77.8% greater proportion in mixture than PPC, although both clovers increased (p < 0.001) in September to similar legume proportions, 663.2 and 876.1 kg/ha, respectively. Clovers with bromegrasses produced 41.9% more forage dry matter yield in summer than clovers with Russian wildryes (p < 0.001), though the latter mixtures had slightly better nutritive value (avg. 7.0% vs. 5.2% crude protein (CP). Clover–MBG exhibited higher (53.6%) *in vitro* organic matter digestibility (IVOMD) than Clover–HBG (51.2%) (p = 0.04). Purple prairie clover with grass or both clovers in mixture with bromegrasses, produced adequate forage biomass for summer and fall grazing, except clovers with Bozoisky RWR, while clovers with both RWR cultivars had acceptable forage nutritive value for summer in this semiarid prairie region.

Keywords: clover, forage yield, grazing, legume, mixtures, nutritive value

1. Introduction

In the semiarid prairie region of the Northern Great Plains of North America, grazing ruminant livestock productivity and sustainability depends on forage dry matter yield (DMY) and nutritive value in late summer and early fall months prior to freezing temperatures that terminate forage growth. Although forage production and quality of alfalfa (*Medicago sativa* L.) and Russian wildrye (*Psathyrostachys junceus* [Fisch.] Nevski) (RWR) mixture can be adequate for summer and fall grazing for cattle (Holt & Jefferson, 1999; Peprah et al., 2021a), alfalfa may cause frothy ruminant bloat which can result in mortalities in grazing cattle (Popp, McCaughey, Cohen, McAllister, & Majak, 2000; Cox, 2013). There is an interest in alternative non-bloating legumes for grazing in this region.

In Virginia, growing crimson clover (*Trifolium incarnatum* L.) in mixtures with annual ryegrass (*Lolium multiflo-rum*) as winter cover crops increased forage biomass and nutritive value (Brown, Ferreira, Teets, Thomason, & Teutsch, 2017). In northern Europe and Canada, white clover (*Trifolium repens* L.), red clover (*T. pratense* L.), timothy (*Phleum pretense* L.), and Kentucky bluegrass (*Poa pratensis* L.) in mixtures created greater herbage yield than sown in monocultures (Sturludóttir et al., 2014). In northeastern Oregon of the United States, red clover was one the primary forb components in the herbage mass with the highest CP content (16.8% CP) and had been readily utilized by cattle on a riparian pasture during a late-summer grazing season (Darambazar, DelCurto, & Damiran, 2013). Although, in southeastern United States, autumn-planted ryegrass or clovers including crimson, arrowleaf (*Trifolium vesiculosum* Savi), ball (*T. nigrescens* Viv.), and red clovers provided minimal to nonexistent forage mass for grazing during the fall (Mullenix & Rouquette, 2018).

White prairie clover (*Dalea candida* Michx. ex Willd; WPC) and purple prairie clover (*D. purpurea* Vent.; PPC) are widely distributed throughout the south and central Prairies and Parklands in Canada (Iwaasa, Li, Wang, Scianna, & Han, 2014) and occur in the Great Plains, south to Wisconsin, Illinois, Tennessee, eastern half of Kansas, Indiana, Montana, Arkansas, Texas, and New Mexico in USA (Wynia, 2008a, 2008b). Purple prairie clover and WPC are forage legumes with moderate to high concentration of condensed tannins (Iwaasa et al., 2014; Li et al., 2014); non-bloating (Li, Tanner, & Larkin, 1996; Berard et al., 2011), and protect plant protein from ruminal microbial degradation (Waghorn, John, Jones, & Shelton, 1987; Aerts, Barry, & McNabb, 1999) resulting in improved protein utilization, live weight gain, and milk yield (Wang, Douglas, Waghorn, Barry, & Foote, 1996; Berard et al., 2011). In addition, condensed tannins are implicated to have antibacterial properties in the digestive tract of animals (Li, Iwaasa, Birkedal, & Han, 2012). Much of the clover growth occurs during July and August but it can complement and improve the forage nutritional profile for grazing livestock during spring to fall grazing periods (Iwaasa et al., 2014). Also, *Dalea* species showed increases on prairie restoration areas in Illinois (Gardner, 2006).

White prairie clover is a native, warm season, herbaceous, perennial legume in the northern Great Plains, produces palatable browse for livestock and wildlife (Damiran, 2005, 2006; Wynia, 2008b), and resumes its growth later than many cool-season grasses and forbs. White prairie clover is mainly adapted to short grass prairies (Khanal, Schellenberg, & Biligetu, 2018), while on tallgrass prairie in Kansas, WPC accumulated very low biomass (~1 kg/ha; Towne & Knapp, 1996).

Purple prairie clover is, also, a native warm season legume which produces excellent forage for livestock and wildlife because of high protein, digestibility, palatability, readily consumed by grazing sheep (*Ovis aries* L.; (Sheaffer, Wyse, & Ehlke, 2009), and mixtures containing PPC with adapted warm-season grasses appeared promising forage crops yielding more forage and increased protein (Posler, Lenssen, & Fine, 1993; Kusler, 2009). In Nebraska, PPC yielded a biomass between 1800 and 2100 kg/ha (Beran, Masters, & Gaussoin, 1999), while the legume had a lower biomass (4 kg/ha) on tallgrass prairie upland soils in the Kansas Flint Hills (Gene Towne & Knapp, 1996). In addition, establishment and persistence of PPC were low and poor at several locations in western Canada (Jefferson et al., 2002). Several native prairie clover germplasm or ecological varieties have been released including, Antelope (WPC) from Plant Materials Centers in Montana and North Dakota (Wynia, 2008b) and AC Lamour (PPC) at Swift Current Research and Development Centre (SCRDC), Agriculture and Agri-Food Canada (AAFC) in Saskatchewan and available in North America for land reclamation and pasture/forage seeding (Iwaasa et al., 2014).

As well, Russian wildrye has adequate nutritive value for mature stock on winter maintenance rations (Sedivec, Tober, Duckwitz, Dewald, & Printz, 2007). ‘Tom’ RWR (TomRWR) developed by SCRDC AAFC, Saskatchewan and registered in 2002, is well adapted to the semiarid prairie region and available as a summer, fall, and early winter pasture (McLeod, Jefferson, Muri, & Lawrence, 2003). ‘Bozoisky-Select’ RWR (BozoiskyRWR) was selected for greater seedling vigor and higher forage yield than cv. Vinall (about 123% of cv. Vinall) by USDA ARS at Logan Utah in 1984 (Anderson & Sharp, 1994) and is very competitive. Meadow bromegrass (*Bromus riparius* Rehm.; MBG) is highly palatable to livestock and wildlife (Sedivec et al., 2007; Lardner, Ward, Darambazar, & Damiran, 2013; Lardner, Damiran, & McKinnon, 2015) and has excellent regrowth and nutritive value for grazing (Holt & Jefferson, 1999; Ogle, St. John, Holzworth, & Jensen, 2006). ‘AC Admiral’ is a MBG cultivar release at Saskatoon Research and Development Centre (SRDC), AAFC in 2009 with improved vigor and greenness in fall and highest relative yield potential reported in Brown (140% of cv. Fleet) and Dark Brown (105% of cv. Fleet) soil zones (Coulman, 2009). Further, hybrid bromegrass (*B. riparius* Rehm × *B. inermis* Leyss; HBG) developed in Canada is a dual-purpose forage for both hay and pasture systems, has good regrowth for grazing and stockpiling and potential for use in beef production system (Ferdinandez & Coulman, 2001) in the Canadian prairies. ‘AC Success’ is a HBG cultivar release from SRDC AAFC in 2003 (Coulman, 2006). Clover or other native legumes would be desirable in seeding with introduced grasses for improving rangelands due to the symbiotic N_2 fixation of the legume, the improved ruminant diet quality and animal performance. However, much of the previous research in this area has focused on stockpiling pure stands of introduced annual and perennial forage species. The objective of this study was to evaluate two native clovers (*Dalea candida* Michx. ex Willd. and *Dalea purpurea* Vent.) in binary mixtures with the introduced grasses when harvested in July and September to simulate late summer or fall stockpile forage.

2. Materials and Methods

2.1 Site Description and Environmental Conditions

A 3-yr (2016-2018) study was conducted at Swift Current, Saskatchewan, Canada, at SCRDC AAFC (50°16′N 107°44′W). Soil at Swift Current is classified as Orthic Brown Chernozem, Swinton association of a silt-loam texture on a gently sloping topography (Saskatchewan Soil Survey, 1990).

In the spring of 2015, soil composite samples were collected at the site from the individual plots to a depth of 15 cm and analyzed for N and phosphorus (P) levels. The soil nutrients' mean contents before planting were 34 kg/ha NO_3-N and 36 kg/ha P_2O_5-P. Based on the soil test recommendations (Government of Saskatchewan, 2016), no fertilizer was applied, while herbicide applications of N-(phosphonomethyl) glycine (Roundup Transorb®) and bentazon (Basagran®) (Monsanto, Creve Coeur, Greater St. Louis, Missouri, USA) were applied at 2.5 and 2.2 l/ha, respectively, for pre-seeding weed control 20 May 2015.

Monthly mean air temperature (℃) and total precipitation (mm) data from 2015 to 2018 and long-term average (LTA; 30-yr, 1971-2000) were obtained from the Swift Current Research and Development Center in Saskatchewan according to Environmental Canada's climate data online (www.climate.weatheroffice.ec.gc.ca) which is based on the weather stations located 1 km from the study site (Table 1). In 2016, total precipitation during the growing season (April to October) was 165% of LTA, while total precipitation recorded in 2017 and 2018 was 47% and 51% of LTA, respectively, in Swift Current. These dry growing seasons at the study site were particularly noticeable from June to August in 2017 and June to September in 2018.

Average monthly temperatures followed mostly similar patterns as the LTAs recorded at the site over the study years, although, they varied in some years with lower temperatures for April and September being observed in 2018 (–24.5% and 71.9% of LTA for April and September, respectively) and higher temperatures observed in October 2015 (150% of LTA). In all, the precipitation data in 2016 reflected a wet season for forage production, as opposed to the dry growing seasons in 2017 and 2018. Overall, these data suggested that the trials were conducted in an environment with similar temperatures over the 3-yr study period, but lower precipitation in the later years compared to the 30-yr average weather condition of this area.

2.2 Experimental Design, Seeding, Stand Establishment, Harvesting, and Sampling

Sixty-four plots were randomly assigned to 1 of 8 replicated (n=4) treatments (WPC–MBG, WPC–HBG, WPC–BozoiskyRWR, WPC–TomRWR, PPC–MBG, PPC–HBG, PPC–BozoiskyRWR, and PPC–TomRWR): 2 clover species/cultivars (WPC cv. Antelope and PPC cv. AC Lamour) in binary mixtures with 3 grass species of 4 cultivars (MBG cv. AC Admiral, HBG cv. AC Success, RWR cv. Bozoisky-Select, and RWR cv. Tom), with two harvesting dates (full bloom and mature stage of clovers).

Most of the binary mixture seeds were obtained from a commercial source (Crop Production Services, Inc., now Nutrien Ag Solutions), however, AC Success HBG and AC Admiral MBG seeds were from SRDC AAFC, and AC Lamour PPC and Antelope WPC seeds were obtained from NRCS Bismarck Plant Material Center (Bismarck, North Dakota, USA). Plots were seeded 28 May 2015. Seeding was completed as a mixed row seeding with a Swift Current plot seeder (Fabro Ltd., Swift Current, SK, Canada) equipped with zero-till disk openers and on-row packing wheels. Seeding rates were 167 pure live seeds per m^2 for each species/cultivar and seeding depth was 1.9 centimeters. Individual plot was consisted of 6 rows (50 seeds per m row) spaced 30 cm apart and 6 m in length or was 1.2×6 m in size (7.2 m^2).

Guard rows of creeping red fescue [*Festuca rubra* L. ssp. *arenaria* (Osbeck) F. Aresch.] were seeded on each side of the trial. The plots were enclosed by a deer fence (Deer Fence Canada Inc., Dunrobin, Ontario, Canada) to prevent grazing by wildlife during the trial. Forage mixtures were harvested once in July (full bloom) or September (mature) during the study years to determine summer and fall grazing potentials of the mixtures. No cutting was done in the seeding year (2015). The harvest dates were 4-5 July and 13 September in 2016, 11 July and 6 September in 2017, and 3 July and 20 August in 2018. Forage cutting was completed with a flail plot harvester (Swift Machine and Welding, Swift Current, SK, Canada).

Table 1. Monthly (April-October), annual, and long-term precipitation and temperature during four consecutive years at Swift Current, SK, Canada

	Temperature, ℃					Precipitation, mm				
Item	2015	2016	2017	2018	LTA[2]	2015	2016	2017	2018	LTA
April	6.1	6.4	4.4	1.2	4.9	12.4	22.0	8.6	7.1	22.6
May	10.1	12.4	12.1	14.4	10.9	2.3	129.7	16.4	14.9	47.9
June	17.1	16.6	15.2	16.9	15.5	16.1	80.4	31.1	20.2	80.9
July	19.0	17.8	20.4	18.9	18.4	96.1	119.0	7.5	32.0	53.3
August	18.2	16.7	18.2	18.5	17.9	49.2	45.9	24.8	28.0	47.8
September	12.6	12.2	13.4	9.2	12.8	39.0	37.1	2.5	41.8	32.5
October	7.8	4.1	4.8	3.8	5.2	33.8	72.1	51.7	10.6	20.3
GS[1]	-	-	-	-	-	248.9	506.2	142.6	154.6	305.3
Annual	-	-	-	-	-	304.0	522.6	189.2	182.3	372.1

Note. [1]GS, growing degrees for the growing season (April-October); [2]Long-term average (1971−2000).

Dry matter yield (DMY), botanical composition, and nutritive value were evaluated to binary mixtures. Forage cutting of a 0.6 × 5.0 m area to a 3-cm stubble height was completed and all clipped samples were separated by live and dead materials, the latter of which was discarded. Dry matter (DM) content was determined by weighing a fresh sample, drying in a forced air oven at 60 ℃ for 48 h to a constant weight, and re-weighing, and a subsample was collected for further laboratory analysis. Dry matter yield was determined by multiplying the DM content by the fresh weight and expressed in kg/ha. Botanical composition was determined by clipping a 1.0-m linear row length (middle row) within each plot and then hand-separating into grass and legume components and the first year-standing dead was discarded. Each component was then dried and re-weighed to calculate its contribution to the total yield. Botanical composition was calculated based on DMY of individual species.

2.3 Nutritive Analysis

Samples were ground to pass through a 1-mm screen using a Wiley mill (Thomas-Wiley, Philadelphia, PA) for further analysis. Forage nutritive value analyses included crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), organic matter (OM), *in vitro* organic matter digestibility (IVOMD), acid detergent lignin (ADL), calcium (Ca), total phosphorus (P), and potassium (K). Sequential NDF and ADF were determined using an ANKOM^{200} fiber analyzer (Model 200; ANKOM; Fairport, NY). The ADL was analyzed through the Klason technique (Van Soest, 1994). Total nitrogen (N) was determined using the micro-Kjeldahl method (AOAC, 2012) and N was multiplied by 6.25 to determine CP content. Calcium concentration was determined using an atomic absorption spectrophotometer (Method 978.02; AOAC, 2012; PerkinElmer, Model 2380, CN, USA), total P was analyzed using a spectrophotometer (Method 946.06, AOAC, 2012; Pharmacia, LKB-Ultraspec® III, Stockholm, Sweden), and K concentration was determined through the method adapted from Steckel and Flannery, (1965). The IVOMD was determined using the procedure developed by Tilley and Terry (1963) and as described by Damiran, DelCurto, Bohnert, & Findholt (2008). Ash was determined by heating at 600 ℃ for 4 h (AOAC method 923.03; AOAC, 2012). Total digestible nutrients (TDN) were calculated using the grass–legume Penn State equation according to Adams (1995).

2.4 Calculation of Nutrient Yield

Nutrients yields as crude protein (CPY); digestible organic matter (DOMY), and total digestible nutrients (TDNY) yields per hectare were calculated by multiplying crop forage yield (kg/ha) by nutrient content (% DM) to allow a comparison of nutrient yield potential for animal feed production among the forage mixtures.

2.5 Statistical Analysis

Initial data analysis employed a split-split-plot design with legume as the main plot, grass as the subplot, and harvest date as the sub-subplot with four (n = 4) replications. However, comparison of forage × harvesting date interactions are not reported, because they were not central to the objective of evaluating the forage mixtures included in this study. Therefore, data are presented by harvesting date. Data were subjected to an analysis of variance (ANOVA) using the MIXED procedure of SAS 9.4 (SAS Institute, 2014) for a completely randomized design and with a 2 × 4 factorial arrangement of treatments as a split-plot design with clover as the main plot and grass as the subplot with four (n = 4) replications.

Firstly, the model used was $Y_{ij} = \mu + Clover_i + Grass_j + (Clover \times Grass)_{ij} + e_{ij}$, where Y_{ij} = response variable; μ = mean; clovers (Clover) and grasses (Grass) in binary mixtures were both fixed effects; $Clover_i$ = clovers included in binary mixtures (WPC cv. Antelope and PPC cv. AC Lamour); $Grass_j$ = grasses included in binary mixtures (MBG cv. Admiral, HBG cv. AC Success, RWR cv. Bozoisky-Select , and RWR cv. Tom); and error was e_{ij}. Each plot was considered an experimental unit for a total of 96 experimental units over the 3-yr study for each harvest date. Analysis showed that the effect of clover and grass was significant ($p < 0.05$), however, clover × grass was not significant ($p > 0.05$) excluding NDF, hence, clover × grass interaction was removed from the model and the data (except NDF data) were re-analyzed to assess only clover and grass effect of forage mixture.

Secondly, within a treatment (forage mixtures), data were, also, analyzed with pair-wise comparisons to determine harvest date effect using the MIXED procedure of SAS 9.4 (SAS Institute, 2014). The model used for the analysis was: $Y_{ij} = \mu + T_i + e_{ij}$; where Y_{ij} was an observation of the dependent variable $_{ij}$; μ was the population mean for the variable; T_i was the fixed effect of the harvest date (July or September); and e_{ij} was the random error associated with the observation ij. Year was treated as a random variable in all analysis because the objective was to characterize forage mixtures the entire growing life and not at individual year points. The differences between treatment means were determined using Tukey's multiple range test and were considered significant at $p < 0.05$ and a tendency declared at $0.05 < p < 0.10$.

3. Results

3.1 Dry Matter Yield and Nutritive Value

3.1.1 White Prairie Clover–Grass

Clover × Grass interaction was not detected ($p > 0.05$) for forage DMY at both harvest dates (Table 2). White prairie clover in July did not produce much biomass with only 0.6% (9.0 ± 2.26 kg/ha) of total DMY of WPC–Grass mixtures (Grass includes MBG, HBG, BozoiskyRWR, and TomRWR), which was still higher ($p = 0.031$) than the legume proportion (0.1%) in PPC–Grass mixtures (2.0 ± 2.26 kg/ha), whereas lower ($p = 0.004$) grass component (1499.6 vs. 2235.7 ± 173.4 kg/ha) was accumulated in WPC–Grass mixtures. Otherwise, clover contribution did not differ within a harvest date ($p = 0.203$ for July and $p = 0.967$ for September) between the clover mixtures with any of the grasses. Nutritional composition of WPC–Grass mixtures did not change during the season due to harvest date with similar low CP (averaged at 5.7 ± 0.40%) and identical NDF values (58.4 ± 0.64%) detected at July and September harvest dates (Table 3). Mixtures of WPC with a grass species (any of the four grasses) at July harvest, produced lower total DMY (1508.6 vs. 2237.7 kg/ha, ±173.61, $p = 0.004$), CPY (77.3 vs. 112.7 kg/ha, ± 6.8, $p < 0.001$), DOMY (778.9 vs. 1148.8 kg/ha, ± 85.0, $p = 0.003$), and TDNY (839.4 vs. 1259.4 kg/ha, ± 94.24, $p = 0.002$), as compared to PPC–Grass mixtures (Table 4).

3.1.2 Purple Prairie Clover–Grass

Lower legume as mentioned above, but higher grass proportion (2235.7 vs. 1499.6 kg/ha, ±173.35, $p < 0.001$) of PPC–Grass mixtures than those of WPC–Grass mixtures were detected at July harvest, although there were no differences at September harvest. Like WPC–Grass, PPC–Grass mixtures did not vary in nutritive value over the growing season remaining at relatively low CP averaged at 6.0 ± 0.40% and high NDF (57.8 ± 0.64%) or had no changes in ADL (8.6 ± 0.33%), IVOMD (52.4 ± 0.43%), TDN (56.3 ± 0.74%), P, K, or Ca concentration over the harvest dates (Tables 3 and 4). For the estimated nutrient yields obtainable from a hectare, the summer productions of PPC–Grass mixtures were greater than WPC–Grass, as mentioned above.

3.1.3 Clover–bromegrass and Clover–Russian Wildrye

Grasses interacted ($p < 0.05$) in forage DMY estimates. Total forage DMY of Clover–MBG (Clover included WPC and PPC) and Clover–HBG mixtures (2412.9 and 2865.7 kg/ha for Clover–MBG and Clover–HBG, respectively, vs. 1012.5 and 1201.4 kg/ha, for Clover–BozoiskyRWR and–TomRWR, respectively, ±245.52, $p < 0.001$; averaged at 2639.3 vs. 1107 kg/ha) and the proportion of bromegrasses at July harvest were higher as compared to total DMY and the proportion of ryegrasses of Clover–BozoiskyRWR and –TomRWR mixtures (2404.1 and 2864.4 kg/ha, of MBG and HBG, respectively, vs. 1003.5 and 1198.6 kg/ha, ±245.16, of BozoiskyRWR and TomRWR, respectively, $p < 0.001$) (Table 2). As well, Clover–MBG had higher IVOMD than Clover–HBG in July (53.6 vs. 51.2%, ±0.64, $p = 0.035$). Clover–HBG mixtures in July tended to exhibit lower Ca concentration than Clover–TomRWR (0.34 vs. 0.5%, ±0.04, $p = 0.061$). There were no differences between the bromegrasses mixed with clovers in yield or legume composition or nutritive components including CP, NDF, ADL, TDN, P or K concentration.

Similarly, no difference was found between Bozoisky–Select and Tom cultivars of RWR in DMY, CP, TDN, IVOMD, or mineral composition in mixtures with clover. Both cultivars in mixtures at July harvest, however, differed from bromegrasses ($p < 0.001$) with lower grass proportion and total herbage production. Also, at July harvest, clovers with bromegrasses produced greater ($p < 0.001$) CPY, DOMY, and TDNY (averaged at 116.2, 1361.2, and 1480.6 kg/ha vs. 73.7, 566.5, 618.2 kg/ha of DM, ±9.58, ±120.17, ±133.27, respectively) than clovers with RWRs (Table 5).

3.1.4 Harvest Date

September harvest resulted in greater forage DMY than July harvest for clovers mixed with RWRs (1012.5 ± 245.5 kg/ha in July vs. 1615.2 ± 282.2 kg/ha in September, $p < 0.05$ and 1201.4 ± 245.5 kg/ha in July vs. 2095.7 ± 282.2 kg/ha in September, $p < 0.01$, for Clover–BozoiskyRWR and Clover–TomRWR mixtures, respectively), while there was a trend of decreased DMY in September from July for Clover–HBG mixtures (2865.7 ± 245.5 kg/ha in July vs. 1971.8 ± 282.2 kg/ha in September, $p = 0.052$) (Table 2). Highest total DMY increase (by 74.4%) in September was obtained for Clover–TomRWR ($p < 0.01$), whereas highest decrease (by 61.3%) in grass proportion was exhibited by Clover–HBG ($p < 0.001$) mixture.

Legume growth was substantial ($p < 0.001$) during the growing season for all treatment mixtures with the proportions ranging from 1.4 to 9.0 kg/ha in July vs. from 663.2 to 876.1 kg/ha in September, specifically, it was up by 99, 99.7, and 99.8% for WPC–Grass, PPC–Grass, and Clover–HBG, respectively.

Table 2. Crop yield of clover-grass binary mixtures in July and September at Swift Current, Saskatchewan, Canada during 2016 to 2018

	DMY, kg/ha					
Entry	Clover		Grass		Total Yield	
Harvest time	July	September	July	September	July	September
Clover						
WPC–Grass[1]	9.0a	876.1***	1499.6a	911.8***	1508.6a	1787.9
PPC–Grass	2.0b	663.2***	2235.7b	1293.0**	2237.7b	1956.2
SEM	2.26	151.00	173.4	152.23	173.61	199.57
Grass						
Clover–MBG	8.8	745.9**	2404.1a	1059.5***	2412.9a	1805.4
Clover–HBG	1.4	863.5**	2864.4a	1108.5***	2865.7a	1971.8*
Clover–BozoiskyRWR	9.0	736.3***	1003.5b	879.0	1012.5b	1615.2*
Clover–TomRWR	2.8	733.0***	1198.6b	1362.7	1201.4b	2095.7**
SEM	3.20	213.55	245.16	215.3	245.5	282.2
	-------------------*p*-value----------------------					
Clover	0.031	0.321	0.004	0.080	0.004	0.553
Grass	0.203	0.967	<0.001	0.465	<0.001	0.653
Clover × Grass	0.194	0.885	0.577	0.923	0.569	0.962

Note. [1]WPC, Antelope white prairie clover; PPC, AC Lamour purple prairie clover; MBG, Admiral meadow bromegrass; HBG, AC Success hybrid bromegrass; BozoiskyRWR, Bozoisky−Select Russian wildrye; TomRWR, Tom Russian wildrye; The different letters within column and within legume and grass indicate significant difference at $p < 0.05$. *, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels between harvesting date within each chemical composition, respectively.

Table 3. Nutrient composition and digestibility of clover-grass binary mixtures in July and September at Swift Current, Saskatchewan, Canada during 2016 to 2018

	% of DM									
Item	CP		NDF		ADL		IVOMD		TDN	
Harvest time	July	September	July	September	July	September	July	September	July	September
Clover										
WPC−Grass[1]	5.9	5.5	58.4	58.4	9.0	8.9	52.3	52.7	56.2	55.8
PPC−Grass	6.2	5.7	57.7	58.0	8.3	9.0	52.1	52.6	57.1	55.5
SEM	0.41	0.38	0.62	0.65	0.43	0.23	0.46	0.40	0.83	0.65
Grass										
Clover−MBG	5.5	5.4	57.3	59.2	8.3	9.0	53.6a	51.3b**	57.1	55.3
Clover−HBG	4.9	5.5	57.9	58.3	8.1	9.3	51.2b	52.9ab*	57.6	55.7
Clover−BozoiskyRWR	7.0	6.0	58.7	56.1	9.3	9.1	52.7ab	53.0ab	55.9	56.1
Clover−TomRWR	7.0	5.6	58.2	59.2	8.8	8.6	51.5ab	53.4ab	56.1	55.5
SEM	0.58	0.54	0.87	0.92	0.61	0.32	0.64	0.56	1.17	0.91
	----------------------------*p*-value----------------------------									
Clover	0.585	0.756	0.457	0.722	0.233	0.688	0.748	0.886	0.457	0.759
Grass	0.022	0.870	0.745	0.061	0.481	0.419	0.035	0.042	0.699	0.922
Clover × Grass	0.883	0.963	0.725	0.033	0.738	0.204	0.335	0.531	0.861	0.387

Note. [1]WPC, Antelope white prairie clover; PPC, AC Lamour purple prairie clover; MBG, Admiral meadow bromegrass; HBG, AC Success hybrid bromegrass; BozoiskyRWR, Bozoisky−Select Russian wildrye; TomRWR, Tom Russian wildrye. The different letters within column and within legume and grass indicate significant difference at $p < 0.05$. *, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels between harvesting date within each chemical composition, respectively; CP, crude protein; NDF, neutral detergent fiber; ADL, acid detergent lignin; IVOMD, *in vitro* organic matter digestibility; TDN, total digestible nutrients.

Table 4. Mineral composition of clover-grass binary mixtures in July and September at Swift Current, Saskatchewan, Canada during 2016 to 2018

	% of DM					
Item	Ca		P		K	
Harvest time	July	September	July	September	July	September
Clover						
WPC−Grass[1]	0.44	0.38	0.11	0.06***	1.21	1.43
PPC−Grass	0.39	0.38	0.10	0.06***	1.17	1.44*
SEM	0.028	0.037	0.012	0.003	0.091	0.082
Grass						
Clover−MBG	0.41ab	0.36	0.10	0.06**	1.27	1.45
Clover−HBG	0.34b	0.40	0.09	0.05**	1.06	1.28
Clover−BozoiskyRWR	0.43ab	0.39	0.12	0.06**	1.25	1.56
Clover−TomRWR	0.50a	0.36*	0.11	0.06*	1.16	1.45
SEM	0.040	0.053	0.016	0.004**	0.128	0.116
	-------------------*p*-value----------------------					
Clover	0.215	0.942	0.516	0.836	0.789	0.879
Grass	0.061	0.934	0.669	0.261	0.639	0.411
Clover × Grass	0.514	0.966	0.995	0.555	0.290	0.787

Note. [1]WPC, Antelope white prairie clover; PPC, AC Lamour purple prairie clover; MBG, Admiral meadow bromegrass; HBG, AC Success hybrid bromegrass; BozoiskyRWR, Bozoisky−Select Russian wildrye; TomRWR, Tom Russian wildrye. The different letters within column and within legume and grass indicate significant difference at $p < 0.05$. *, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels between harvesting date within each chemical composition, respectively.

Table 5. Crude protein, digestible organic matter and nutrients yield of clover-grass binary mixtures in July and September at Swift Current, Saskatchewan, Canada during 2016 to 2018

	kg/ha of DM					
Item	CPY		DOMY		TDNY	
Harvest time	July	September	July	September	July	September
Clover						
WPC−Grass[1]	77.3b	81.9	778.9b	938.4	839.4b	979.2
PPC−Grass	112.7a	89.0	1148.8a	1029.0	1259.4a	1064.5
SEM	6.77	7.44	84.97	104.17	94.24	105.88
Grass						
Clover−MBG	110.5ab	80.3	1270.3a	922.0	1345.6a	977.0
Clover−HBG	122.0ab	85.8*	1452.0a	1042.0	1615.6a	1063.5*
Clover−BozoiskyRWR	67.92c	80.1	524.5b	861.0	563.5b	903.3*
Clover−TomRWR	79.5bc	95.7	608.5b	1109.8	672.9b	1143.5**
SEM	9.579	10.53	120.17	147.32	133.27	149.74
Clover	<0.001	0.498	0.003	0.540	0.002	0.571
Grass	<0.001	0.695	<0.001	0.626	<0.001	0.694
Clover × Grass	0.140	0.911	0.518	0.954	0.465	0.954

Note. [1]WPC, Antelope white prairie clover; PPC, AC Lamour purple prairie clover; MBG, Admiral meadow bromegrass; HBG, AC Success hybrid bromegrass; BozoiskyRWR, Bozoisky−Select Russian wildrye; TomRWR, Tom Russian wildrye. CPY, crude protein yield; DOMY, digestible organic matter yield; TDNY, total digestible nutrients yield. The different letters within column and within legume and grass indicate significant difference at $p < 0.05$. *, **, *** Significant at the 0.05, 0.01, and 0.001 probability levels between harvesting dates within each chemical composition, respectively.

Whereas grass proportion at September harvest declined for all excluding clover mixtures with RWRs (by 39.2%, p = 0.001; 42.2%, p = 0.003; 55.9%, p = 0.001; and 61.3%, p < 0.001 for WPC–Grass, PPC–Grass, Clover–MBG, and Clover–HBG mixtures, respectively).

Nutritionally, clover mixtures with grass did not vary over the harvest dates. However, a significant Clover × Grass interaction (p = 0.033) was detected for NDF concentration at September harvest (data not shown). There was a trend for WPC–MBG and –TomRWR mixtures exhibiting the highest NDF contents (60.6 and 60.4 ± 1.30% for WPC–MBG and WPC–TomRWR, respectively), while WPC–BozoiskyRWR containing the lowest NDF content (54.0 ± 2.01%) in September (p = 0.061) with a tendency of declining (p = 0.078) from July (59.0 ± 0.88%) (data not shown). Otherwise, there was no difference between Bozoisky and TomRWR cultivars in clover mixtures for DMY or for several nutritive parameters. During the growing season, Clover–MBG decreased in IVOMD (p < 0.01) by September harvest, while Clover–HBG and –TomRWR mixtures increased (p < 0.05).

Also, Clover–MBG had higher IVOMD than Clover–HBG (53.6 vs. 51.5%, ± 0.64) in July, but lower than Clover–TomRWR mixtures (51.3 vs. 53.4%, ± 0.56) in September (p = 0.042). Reduced total P content (by 44.4-50%) was observed from July to September in all mixtures (0.09-0.12%, ±0.02 in July vs. 0.05-0.06%, ±0.004 in September, p < 0.01). The Ca concentration at September harvest declined from July harvest by 28% in Clover–TomRWR mixtures (0.36 ± 0.05% in September vs. 0.50 ± 0.04%, in July p < 0.05), whereas 23.1% increase in K concentration in PPC–Grass mixtures (1.2 ± 0.09% vs. 1.4 ± 0.08%, p < 0.05) was detected from July to September.

4. Discussion

4.1 Forage Dry Matter Yield and Nutritive Value

4.1.1 White Prairie Clover–Grass

In the companion study (Peprah et al., 2021b), there were 18 forage mixture treatments of binary combinations consisting of 4 legume species that included alfalfa cv. AC Yellowhead and 3 grass species harvested at the same dates as in the current study. Hence, for a comparison purpose only, we are using the alfalfa (cv. AC Yellowhead)-grass mixture from the companion study as a check forage in the current study.

White prairie clover in binary mixture with grass accumulated 58% and 5.4% less total forage DMY and legume contribution of WPC at July harvest was far from being comparable to check forage (0.6% vs. 34.7%), i.e., almost 60 times less than that of check forage, whereas in September it increased with 14.2% units higher of WPC (49.0% vs. 34.8%).

At Swift Current, SK, Canada, Serajchi et al. (Serajchi, Schellenberg, Mischkolz, & Lamb, 2018) reported that WPC in binary mixture with western wheatgrass (*Pascopyrum smithii* (Rydb.) Löve) yielded approximately 1300 and 1400 kg/ha in early-July and late-August, respectively, and CP did not change over the harvest dates remaining at around 6% (Serajchi et al., 2018), compared to which, the WPC–Grass binary mixtures in the present study, produced 208 and 388 kg/ha greater at July and September harvests, respectively, and consistent CP values.

As the legume composition at July harvest indicated, both clover species in the present study were not able to develop well in the summer, they did better only later in the season though were still dominated by the grass (grass comprised 99.4% and 51.0% of DMY of WPC–Grass mixture in July and September, respectively), suggesting that the nutritive value of the mixtures at summer harvest illustrated that of the grass component and with the legume component reaching 49% of DMY by the fall, though both grass and legume may have likely been at nutritionally declining stage at this time.

Comparing seeding of native grasses and forbs in Montana, Majerus, Kilian, & Scianna (2020) obtained good white prairie clover establishment and performance producing 92 kg/ha biomass and had moderate basal cover (4%) and plant density (2 plants/m^2) when seeded with other forbs and grasses. A study from Swift Current, SK demonstrated that WPC can be present at more than 50% in mixture with Nodding bromegrass (*Bromus porter* (Coult.) Nash), while it was less than 10% in mixture with Western wheatgrass (*Pascopyrum smithii* (Rydb.) Löve) indicating that the grass species in the mixture will affect its contribution to the forage (Serajchi et al., 2018). Likewise, Jefferson et al. (2002) observed a grass cultivar effect on clover biomass productivity at western Canadian prairie locations. The three grass species in July, in the current study, performed more like Western wheatgrass in competition with WPC in Serajchi et al. (2018).

Also, white clover (*Trifolium repens* L.) on a coarse loamy soil in Nova Scotia, Canada, seeded in binary, tertiary, and quaternary mixtures with common pasture grass species contributed the lowest proportion of the total herbage biomass (ranging from 5.8 to 25.1%, with an average of 15.5% in binary mixture) and was affected by sward mixture with inferior yield of clover in Kentucky bluegrass (*Poa pratensis* L.)-containing mixtures (Papadopoulos et al., 2012). Others, however, reported that regardless of companion grass species, mixtures with white clover were productive with 11835-13303 kg/ha of annual DMY on loamy-sand soil in Denmark where plots were irrigated to avoid drought stress, and white clover proportion in binary mixtures with perennial ryegrass (*Lolium perenne* L.) or timothy (*Phleum pratense* L.) or meadow fescue (*Festuca pratensis* Huds.) or hybrid ryegrass (*Lolium × boucheanum* Kunth) harvested in July was in the range of 30-50% of DMY, decreased to 20-30% harvested in August and October, ranging 22-34% during May to August, and contained around 20% CP and 40% NDF (Elgersma &Soegaard, 2016). On a pasture of predominantly perennial ryegrass and white clover, with 16380 kg/ha production near Hamilton, New Zealand, the clover content was measured at 15.2% (Papadopoulos et al., 2012).

Nutritionally, WPC–Grass mixtures contained 31.4% lower but 5.8% higher CP in July and September harvests, respectively, and 10.4% greater NDF in July and 6.3% greater ADL in September, as compared to check forage. Differences were minimal (under 5%) in ADL in July, in IVOMD, TDN or P concentration at both harvest dates between WPC–Grass mixtures and check forage, however, Ca and K concentrations were 42.1% and 6.2% lower, respectively, in July, but K was 26.6% higher in September. Elsewhere, WPC consistently had higher OMD compared to PPC at any phenological stage, with 51.3% OMD, 12.9% CP, and 45.9% NDF at flowering grown near Swift Current, SK, (Iwaasa et al., 2014), while WPC grown in Missouri contained 12.7% CP and 50.7% NDF (McGraw, Shockley, Thompson, & Roberts, 2004), of which OMD value was similar, but CP was twice as high and NDF was lower; compared to the values in the current study. Also, at Swift Current, SK, six populations of WPC exhibited differences in CP (ranged from 15 to 18%) and NDF (ranged from 34 to 41%) at the bloom stage, while little or no differences at maturity stage (ranged from 6.2 to 7.1% and from 45 to 52% for CP and NDF, respectively (Khanal, Schellenberg, & Biligetu, 2018), the latter partly agreed with the current study in that the clover species remained unchanged in nutrients at maturity.

Wynia (2008b) noted that WPC is adapted to locations with 250 to 450 mm of growing season precipitation. Precipitation in 2017 and 2018 at the current study site was well below this level with 175 mm in 2017 and 128 mm in 2018 from April to October. Therefore, water stress may account for the extremely low forage production and presence of WPC in July in the current study. Our results further conflicted in part with the findings that WPC had low forage biomass but good forage nutritive value, with 12.7% protein and was more digestible (had lower ADF) than commonly used introduced forage legumes (McGraw et al., 2004). Overall, as indicated in the current study, WPC may have better competitive ability as compared to PPC in mixture with introduced grass, that would be exhibited stronger in the fall.

4.1.2 Purple Prairie Clover–Grass

Purple prairie clover produced 64.9% less forage yield in September as compared to check forage. Since at July harvest legume proportion of PPC was almost nonexistent in the mixture, it was not comparable with check forage (0.11 vs. 34.7% of DMY), while at September harvest it was closer (29.5 vs. 34.8% of DMY) to check forage. As well, the lack of establishment or competitive ability of PPC with grasses was noted by others; PPC mixed with native grasses delivered biomass ranging from zero at Swift Current-irrigation to 1000 kg/ha at Brandon-sandy soil site (Jefferson et al., 2002), in Minnesota, second-year biomass yield of legume for PPC in mixture with little bluestem (*Schizachryium scoparium* (Michx.) Nash) was 1100 kg/ha (Fischbach et al., 2006), low proportion of PPC (21%) in binary mixture with Bluebunch wheatgrass (*Pseudoroegneria spicata* (Pursh) Löve) but up to 58% legume in mixture with sideoats grama (*Bouteloua curtipendula* (Michz.) Torr.; (Serajchi et al., 2018) and PPC made up a very small portion of the mixtures with native cool-season and warm-season grasses on seeded pastures near Swift Current, SK (Schellenberg, Biligetu, & Iwaasa, 2012).

Purple prairie clover was, also, less productive than alfalfa and less competitive in mixtures with native shrubs (Schellenberg & Banerjee, 2002). Partly on the contrary to our study, PPC was readily established with comparable nutrient content to that of alfalfa and sainfoin under dryland condition, but its yearly yield was substantially lower than conventional legume forages (Wang et al., 2019). The results on PPC in mixture with tame grass in our study mostly agreed with the aforementioned studies, and particularly, the summer yield of PPC in mixtures coincided with that Jefferson et al. (2002) reported at Swift Current-irrigation site. Clover contribution of PPC in binary mixtures in the current study, expectedly, was much lower compared to the DM yields of 2014 and 2297 kg/ha of PPC grown alone under dryland condition at full flower and late flower stages, respectively (Wang, Iwaasa, Acharya, & McAllister, 2019).Iwaasa, Xu, Acharya, & McAllister, 2019).Xu, Acharya, & McAllister, 2019). Regarding nutritional composition, PPC–Grass mixtures had 9.1% higher NDF, 27.9% lower CP, and 34% lower Ca concentration in July, but 9.6% higher CP content in September than check forage. Otherwise, there was minimal difference (<5%) in ADL, IVOMD, or TDN between PPC–Grass and check forage. As well, no difference in P or K concentration was detected between all mixture/treatments at the harvest dates and check forage. Conversely, Ca concentration of PPC–Grass mixtures differed by almost half (~50% lower) the amount check forage contained, remaining unchanged over the harvest dates.

Elsewhere, PPC in monoculture exhibited lower NDF (47.3%) and higher CP concentration (15.2%) than other legumes including WPC, when harvested at early flowering stage in central Missouri (McGraw et al., 2004), while Iwaasa, Sottie, Wang, and Birkedal (2016) in Swift Current, SK found higher CP (16.9% vs. 14.2%) and OMD (58.8% vs. 51.3%) in WPC than in PPC harvest-ed at full flower/seed set stage and similar NDF (38.4%, WPC and 40.7%, PPC). As well, similar NDF and CP contents were reported at semiarid prairie in Swift Current, SK, 53.7% NDF and 9.8% CP during flowering (Iwaasa et al., 2014) and 52.6% NDF and 10% CP at full flower stage on rehabilitated native mixed grass pasture, with NDF and ADF contents increased, while CP decreased as PPC matured (Peng et al., 2020). Whereas, grown on irrigated plots in Orthic Brown Chernozem soil in Lethbridge, AB, harvested at full-flower stage, freeze-dried green chop of PPC contained on average about 16% CP, 44% NDF, and 8% ADL (Peng et al., 2020). As the clover was grown alone in these studies, the lower NDF and higher CP in PPC was expected. Comparable to our findings were though the relatively high NDF concentrations in the native legumes compared to common introduced forage legumes reported in McGraw et al. (2004).

In our study, the CP and IVOMD values of PPC–Grass mixtures at July harvest were comparable to those values (6.0% CP and 50.9% IVDMD) of PPC–Sideoats grama (*Bouteloua curtipendula* Michx.) or (51.5% IVDMD) of PPC–Indiangrass [*Sorghastrum nutans* (L.) Nash] binary mixtures from July harvests near Manhattan, Kansas (Posler et al., 1993). Furthermore, PPC–Grass mixtures harvested at full bloom in the current study had greater IVOMD as compared to the OMD (40.6%) determined in PPC at flowering in the Orthic Brown Chernozem soil (Iwaasa et al., 2014) and similar or higher to the IVDMD values (50.9 or 46.3%) at full flower stage for mixtures that included 25 or 50% of PPC and cool-season native grasses (Peng et al., 2020) and as the latter study found IVDMD decreased with increasing PPC percentage in mixture. Conversely, on a very fine sandy loam soil in Kansas, PPC in binary mixture with warm-season grass did not influence IVDMD of mixtures (Posler et al., 1993). On the other hand, organic matter digestibility and protein digestibility of a mixture of alfalfa and PPC in a ratio of 40:60 (DM basis Mix) were lower than those of alfalfa (Huang et al., 2015). Nevertheless, our findings on IVOMD, P, ADL and TDN contents of PPC–Grass mixtures were adequate for grazing beef cows in the first and second trimester of gestation (NASEM, 2016).

4.1.3 Comparison of White and Purple Prairie Clovers

Studying native legumes near Columbia, Missouri, McGraw et al. (2004) reported similar forage yield, 10.2 and 11.6 g/plant at flowering and 5.7 and 22.1 g/plant at mature stages, for WPC and PPC, respectively, and this was partially in agreement with the results in the present study. Still, literature have been conflicting on growth performance of the two clover species; among three *Dalea* species ranked on germination PPC cv. AC Lamour was the greatest and WPC cv. Antelope the intermediate (Schellenberg & Biligetu, 2015) and WPC and PPC had 78% vs. 65% survival and 76% vs. 237.2% selection differential for biomass, respectively, in Swift Current, SK, Canada (Khanal et al., 2016), while in Stephenville, Texas, the United States, *Dalea candida* produced 124% more herbage biomass and 80% greater root biomass than *D. purpurea* (Girgin, 2019).

Difference between the two clovers in legume proportion in the mixtures obtained in the current study (77.8% and 32.1% greater WPC proportion than PPC in July and September harvests, respectively,) was more related to the findings of Girgin (2019) than of the others. Additionally, the legume proportions in September for WPC–Grass (49%) and PPC–Grass (29.5%) mixtures in the present study differed by 19 and 9% units higher for WPC while PPC proportion was at the lower range value, respectively, in comparison to the optimal legume percentages of 30–40% in the harvested biomass achieved in Sanderson, Brink, Stout, and Ruth (2013) study on grass-legume proportions in forage seed mixtures that included white, red, and kura clovers (*Trifolium ambiguum* L.), which revealed, also, that the differences in yield were related to the dominant species in the mixture.

Moreover, CP content in clovers with RWRs at July harvest was on average 25.7% greater (although statistically not significant) than in clovers with bromegrasses, which agreed to Russian wildrye being high in protein but did not agree to it retaining higher CP content than most grasses after maturity (Ogle et al., 2012). There were trends for lower (6.4% units) NDF content in WPC–BozoiskyRWR ($p = 0.078$) than in WPC–TomRWR in September and for Clover–TomRWR containing greater (0.16% units) Ca concentration ($p = 0.061$) than Clover–HBG in July, the latter was 55.3% lower as compared to check forage.

As well, in an irrigated, 4-year trial at Powell, Wyoming, alternate-row yield of Bozoisky-Select Russian wildrye paired with alfalfa was 6913.6 kg/ha (USDA NRCS, 2013), compared to which the summer and fall yields of this cultivar in mixtures with clover in the present study were substantially (>3 times) lower. As both 'Bozoisky-Select' and 'Tom' cultivars of RWR were originally selected for similar traits, albeit at different locations and countries (first in Utah, USA and latter in Saskatchewan, Canada), performance of BozoiskyRWR in mixture with clover was not different of TomRWR nutritionally and yield-wise (in the summer) in this semiarid region of western Canada, however, numerically the first yielded less than the latter in the fall.

Clover–HBG mixtures exhibited numerically 15.8% more forage yield than Clover–MBG mixtures and both grasses with clovers yielded 27% higher than RWRs in clover mixtures, the latter partly contradicted with Holt and Jefferson (1999) who reported that MBG and alfalfa pastures produced similar forage DMY to RWR and alfalfa pastures. Russian wildrye has a caespitose growth form while both HBG and MBG are rhizomatous grasses. When compared to other introduced grasses, Russian wildrye is slow to establish. When seeded in rows, rhizomatous grasses can fill the interplant space with new shoots originating from rhizome meristems when sufficient resources permit.

Therefore, rhizomatous grasses are more competitive with legume associates in this semiarid environment where seasonal droughts create resource competition (Biligetu, Jefferson, Muri, & Schellenberg, 2014; Peprah et al., 2021). Also, Jefferson et al. (2002) seen a grass cultivar effect on PPC biomass productivity when seeded several native warm-season and cool-season grass species with only legume as PPC and they further stated that while the PPC biomass was low, the PPC grown with warm-season grasses produced more biomass than clover grown with cool-season grasses suggesting that the cool-season grasses are more competitive in mixture with PPC than the warm-season species.

The early growth of cool-season grasses that was observed in the current study could reduce light quality and quantity reaching clovers. However, as others implied, improved seeding management (Kenno, Brick, & Townsend, 1987) may alleviate stand establishment problems of binary mixtures of the prairie clovers with grass. For example, forage yield of RWR with legumes can be increased by seeding in alternate rows (USDA NRCS). Thus, as our results indicated, HBG in native clover mixture has more potential in the semiarid Brown soil zone of western Canada for beef cattle pasture production. Our findings, also, suggested that PPC and BozoiskyRWR appeared to have reduced competitive effects on the grass and legume species, respectively, in the binary mixtures studied.

The interest in using these native legumes as non-bloating alternatives to alfalfa for late summer and fall grazing will be restricted by these limitations in forage yield, plant persistence in grass mixture, and lower forage nutritive value compared to alfalfa. Freedom for any potential bloat risk with these legumes will be weighed relative to their performance to support cattle live weight gains in comparison to the bloat risk of alfalfa. The decision of individual producers must account for these performance limitations when contemplating the substitution of these native legume species for alfalfa in binary mixtures for late summer and early fall pastures for beef cattle.

The goal of the beef producer is paramount to the selection of species for stockpile grazing in the late summer and fall. If yield was the major goal of the producer, then PPC–Grass, or either WPC or PPC with MBG or HBG mixtures would be the top choice. However, if nutritive value was the goal, then both legumes in mixtures with either one of the two RWR cultivars seem would be adequate for summer grazing, while in mixtures with either one of the three grass species would not provide adequate nutritive value for dry beef cow for fall. Furthermore, CP and TDN yields expressed in kg/ha are of significant importance to producers for determination of winter feed (hay) value and supplemental protein feed. In that regard, also, PPC–Grass mixtures showed advantage producing 45.8 and 50% higher CPY and TDNY, respectively, and 47.5% more DOMY in the summer as compared to WPC–Grass. Likewise, McGraw et al. (2004) concluded that it does not appear that native legumes would be a good substitute for the common, introduced legumes when forage nutritive value is the only consideration. If species diversity and ecological restoration is the primary goal, the WPC and PPC can be used as the legume component but grazing animal performance will likely be less than as it is with alfalfa.

In addition, the results of the current study demonstrated that during the summer and fall, binary mixtures of PPC–Grass (2237.7 kg/ha in July and 1956.2 kg/ha in September) and of both clovers with HBG (2865.7 kg/ha in July and 1971.8 kg/ha in September) produced DMY above or at the minimum requirement (2000 kg/ha) for forage production for fall grazing (Aasen & Bjorge, 2009). On the contrary though, WPC–Grass (1508.6 kg/ha in July and 1787.9 kg/ha in September), Clover-BozoiskyRWR (1012.5 kg/ha in July and 1615.2 kg/ha in September), Clover–TomRWR (1201.4 kg/ha in July), and Clover–MBG (1805.4 kg/ha in September) mixtures failed to meet the minimum requirement possibly because of their more vulnerability to the dryer conditions, suggesting these mixtures may not be good option for late summer and fall grazing. The lower precipitation experienced during the growing seasons of 2017 and 2018 compared to 2016, had a significant effect on both yield and nutritive value, thereby making most binary mixtures unable to meet the nutrient requirements for fall grazing by beef cattle.

According to NASEM (2016), the CP and TDN requirements for mature cows and heifers in pre-calving, postpartum, lactating and pregnant, and mid-gestation periods ranged from 6.2 to 12.9% and 44.9 to 64.5%, respectively. In the current study, only mixtures PPC–Grass and clovers with RWR of both cultivars at July harvest were in the CP range requirement, the latters were, also, at the NRC (2000) recommended level (7% CP), as well, TDN in all binary mixtures were in close range to each other (55.3-57.6%) meeting the nutrient requirement. Further, as Van Soest (1965) suggested, when NDF concentration increases to more than 55 to 60% of the DM it may limit intake because of rumen fill. Nevertheless, NDF in the mixtures in the present study, averaged at 58%, thus were of medium nutritive value according to NASEM (2016) nutrient requirement. Inability of the other binary mixtures in the present study, to meet the CP requirement of beef cattle indicates their limitations for late summer and fall grazing under dryland farming conditions, especially in dryer than usual years.

5. Conclusions

The addition of white and purple prairie clovers as native forage legumes in mixtures with introduced grass species resulted in lower herbage yield and nutritive value in summer, yet these measures were comparable to or higher in fall compared to conventional legume–grass mixtures. Clover mixtures with Bozoisky–Select or Tom cultivar of Russian wildrye could be adequate summer forage based on the nutritive value, while clover mixtures with Admiral meadow bromegrass or AC Success hybrid bromegrass were suitable based on the yield. Overall, current study results suggest that white and purple prairie clover in mixture with hybrid bromegrass, along with purple prairie clover with either of the three grass species can offer sufficient forage production. Although forage nutritive value of these mixtures was average, the yields per hectare of crude protein, total digestible nutrients, and digestible organic matter were acceptable for summer or fall grazing in southwest Saskatchewan, Canada. Finally, future research should focus on evaluating white and purple prairie clover-grass mixtures under grazed conditions for forage persistence and animal performance in different soil zones.

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Evaluation of Post-weaning Efficiency in Nellore-Angus Crossbred Steers through Model Predicted Residual Consumption

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Abstract

The objective of this work was to evaluate efficiency traits of Nellore-Angus crossbred steers (n = 349) on feed. Steers were fed a grain-based diet beginning at approximately 12 months of age for an average of 140 days. Contemporary groups were born in the fall or spring of 2003 through 2007 in full-sibling embryo transfer families or half-sibling families all sired by the same bulls. Individual intake was measured and weights were recorded to permit calculation of average daily gain. Residual feed intake (RFI) was estimated as the residual of models employing regressions on metabolic mid-test weight and ADG. An additional efficiency metric was also constructed and evaluated: model predicted residual consumption (MPRC). Mixed linear models were used to analyze daily dry matter intake, average daily gain (ADG), metabolic mid-test weight, RFI, and MPRC. Large positive associations of DMI with MPRC and RFI were identified along with low positive associations between metabolic mid-weight with ADG and MPRC. Genome wide association analysis revealed 5 regions associated with DMI, but none for the other traits analyzed. Residual feed intake values varied greatly between the contemporary group value and the overall value for the steers, showing the calculation's dependency on the reference population. However, MPRC as based upon a standardized population, did not fluctuate. More selection phenotypes and strategies are needed for large-scale improvements in global beef cattle production sustainability. The stability of the MPRC metric could be beneficial for future feed efficiency research across multiple and diverse contemporary groups, and diverse production environments.

Keywords: *Bos indicus* crosses, feed efficiency, residual feed intake, post-weaning growth

1. Introduction

Many life cycle assessments have shown potential of reduced greenhouse gas emissions through improved production efficiency from various beef cattle production management strategies (Foley et al., 2011; Stackhouse-Lawson, Rotz, Oltjen, & Mitlöehner, 2012; Nguyen et al., 2013; Wang, Teague, Park, & Bevers, 2015); however, efficiency differences among individual animals is also an important sustainability consideration. Feed intake in cattle can be adjusted for weight and weight gain (Koch et al., 1963), and residuals from such a model would be theoretically independent of weight, ADG, and other modeled effects. For an individual, this deviation could represent an unbiased phenotype of efficiency, and is known as residual feed intake (**RFI**). Residual feed intake has been reported as moderately heritable (Koch et al., 1963; Arthur et al., 2001; Crews, 2005), and several have proposed that adequate variation exists in RFI for selection (Archer & Bergh, 2000; Herd & Bishop, 2000; Basarab et al., 2003). Nkrumah et al. (2006) proposed lower RFI reduced enteric methane production through more efficient nutrient utilization. However, concern may exist from some cattle breeders if selection for reduced RFI in steers caused undesirable decreased feed intake breeding values for heifer half-siblings, especially for extensive winter grazing scenarios. It also could be expected that contemporary group effects might be profound with RFI rankings. Especially in the limited sample sizes inherent in experimental agriculture, it is not difficult to imagine that an individual classified as 'efficient' in one contemporary group, could rank unfavorably and be 'inefficient' in another group. It is important to know if the rank in the contemporary group is a good representation of the rank in the population. The statistical adjustment of contemporary group for RFI is trusted to remove such effects.

Difficulties in interpretation of RFI results are emphasized when *Bos indicus* breeds such as the American

Brahman are included in a study with *Bos taurus* cattle (e.g., Elzo et al., 2009). In most scenarios, *Bos indicus* cattle have lower intake relative to expectation, and thus often have lower (more desirable) RFI relative to other breeds. However, this lower level of intake also results in relatively lower growth rates, such that cost of production (feed conversion ratio) is less desirable in these types despite their lower RFI. Evaluation of relative feed utilization efficiency might be better accomplished with another metric that could minimize the difficulties associated with RFI. Improving efficiency (reducing feed demand) and increasing productivity (beef produced per unit of energy consumed in the entire production system) are important components of improving measures of sustainable production; these considerations are particularly important in poverty-stricken and resource-limited regions, many of which rely on tropically adapted cattle populations. Metrics that allow identification of more efficient and productive *Bos indicus* cattle and their crosses may also become more important in temperate areas that may experience an increase in temperatures.

A research population of F_2 Nellore-Angus was established in Central Texas in the mid-2000s to discover genomic regions associated with multiple beef production and efficiency traits. Phenotypes related to post-weaning growth and feed efficiency were recorded for steers from that population. The objectives of this project were to: (1) assess an efficiency metric based on a standardized nutrition model, especially in comparison to RFI and its components, (2) characterize family performance for feed efficiency traits, (3) assess correspondence of efficiency traits with carcass and animal temperament, and (4) assess association of SNP with the efficiency phenotypes.

2. Materials and Methods

2.1 Animals

All procedures involving animals were approved by the Texas A&M University Institutional Animal Care and Use Committee. The animals in the overall project population were described previously in detail (Riley et al., 2013; Hulsman Hanna et al., 2014). In brief, those with records in this research were steers sired by 4 F_1 Nellore-Angus bulls from 14 full-sibling F_2 Nellore-Angus families produced by embryo transfer and 4 half-sibling families (from half *Bos indicus-Bos taurus* dams). These steers (n = 349) were born in either fall (embryo transfer calves only) or spring from 2003 to 2007.

After weaning, calves grazed pastures for approximately 130 days. Warm season pastures included coastal bermudagrass (*Cynodon dactylon*), Eastern gamagrass (*Tripsacum dactyloides*), and Kleingrass (*Panicum coloratum*). Steers were supplemented with coastal bermudagrass hay or sorghum-sudangrass (*Sorghum bicolor*) hay in the winter. After this growing period, calves were placed in pens and fed a grain-based diet (Table 1), and individual feed intake was evaluated using a Calan gate system (American Calan, Inc., Northwood, NH) beginning at 11 to 13 months of age. These facilities were either soil surfaced pens with bunks under a shade structure (Year 1) or concrete surfaced pens with shade over 50% of the pen area. Feed was offered *ad libitum*, and refused feed was collected and weighed at 7-day intervals, with fresh feed offered if there was substantial buildup of refused feed. The diet was periodically checked for DM content, which averaged 90%. A few steers refused to eat from the Calan gate bunks, and their records were excluded from analyses. Steer weights were recorded every 28 days while on feed. Steers were fed to achieve a 12^{th}-rib back-fat thickness of 0.9 cm based upon visual appraisal. The average time on feed was 140 days and ranged from 128 to 151.

Table 1. Ration formulation[1]

Ingredient	%
Ground milo	20.00
Ground corn	31.25
Cottonseed meal	9.00
Cottonseed hulls	25.00
Molasses	10.00
Premix[2]	3.00
Ammonium chloride	0.25
R-1500[3]	1.50

[1] Expressed as a percent on an as-fed basis

[2] Composition of premix: ground limestone, 60%; trace mineralized salt, 16.7% (NaCl, 98%; Zn, 0.35%; Mn, 0.28%; Fe, 0.175%, Cu, 0.035%, I, 0.007%, Co, 0.007%); mono-dicalcium phosphate, 13%; potassium chloride 6.7%; Vitamin premix, 3.3% (vitamin A, 2,200,000 IU/kg; vitamin D, 1,100,000 IU/kg, vitamin E, 2,200 IU/kg); Zinc oxide, 0.33%.

[3] R-1500 contains 1.65 g monensin sodium (Rumensin™) per kg.

2.2 Traits Evaluated

Observed dry matter intake (**DMI**) was regressed on ADG and mean metabolic BW ($BW^{0.75}$) to yield residual feed intake (**RFI**) values within contemporary groups for a 140-day feeding period. Using the NRC (1996) beef cattle model, daily feed intake of each steer was predicted based on observed weight gain and standardized input for animal type, age, sex, condition, and breed. This model-predicted intake was subtracted from observed DMI and the difference defined as **model predicted residual consumption** (**MPRC**). Similar to RFI, those animals that consumed less than predicted (and thus, were more efficient) had negative values of MPRC. Unlike RFI, this measure used the same standard model to predict intake across all contemporary groups, rather than estimating a unique regression model within each group.

2.3 Genotypes

The BovineSNP50v.1 assay (Illumina Inc., San Diego, CA) was obtained for all project animals and was previously described in detail by Tolleson et al. (2017). The quality-edited set of SNP markers used in genome-wide association analyses was 34,980.

2.4 Statistical Analyses

Preliminary analyses were used to construct final models for each trait. Investigated fixed effects included steer birth year, birth season, feedlot pen (a block effect), age of dam (nursing dam for embryo transfer calves), and age in days as a covariate. Random effects investigated included additive direct and maternal additive effects. Single-trait analyses were conducted with ASReml (Gilmour, Gogel, Cullis, & Thompson, 2009). Additional analyses were conducted to deliberately assess the effect of family as designed; those additional analyses did not include modeled random genetic effects other than the residual variance.

Genome-wide association analyses were conducted using JMP Genomics (SAS Inst., Inc., Cary, NC). These consisted of fixed regressions on genotypic values (number of copies of the minor allele at each locus) and inclusion of the genomic relationship matrix (Yu et al., 2006) to model the covariances among animals. The false discovery rate (FDR) was controlled per methodology of Benjamini & Hochberg (1995). Map coordinates of associated SNP were obtained from the bovine reference assembly UMD-3.1 (Zimin et al., 2009), and the nearest gene to each SNP was identified using the R package MAP2NCBI (Hulsman Hanna & Riley, 2014).

The relationship between RFI and MPRC was illustrated by calculating simple correlation and Spearman’s rank correlation between the two traits and through comparison of individuals’ classification for each respective trait. Analysis of RFI and its components was done by comparing contemporary group RFI and classification to an overall RFI and classification. Group and overall classification was also compared for MPRC.

3. Results

3.1 Descriptive Statistics and Family Differences

Summary statistics for the evaluated steer traits are presented in Table 2. For all traits, likelihood ratio tests indicated that the only random term supported was additive genetic effects. From preliminary analyses, contemporary groups were designated as combinations of year and season of birth. This effect ($P < 0.001$ all traits) included 9 levels, and ranged from 13 to 63 steers per group. Age of dam was not a significant source of variation for these traits. Linear regressions of trait on steer age in days ($P < 0.04$) indicated that older steers had heavier metabolic mid-weight, lower ADG, and higher (worse) MPRC (0.05 ± 0.008 kg, –0.07 ± 0.03 kg/d, and 0.007 ± 0.003, respectively), but steer age was not influential ($P > 0.29$) for DMI or RFI. Estimates of additive and residual variances were 3.64 and 3.16 kg^2, 0.003 and 0.007 kg^2, 0.15 and 0.35 kg^2, 0.14 and 0.67 $units^2$, and 0.07 and 0.67 $units^2$ for metabolic mid-weight, ADG, DMI, MPRC, and RFI, respectively.

Table 2. Descriptive statistics of evaluated traits (n = 349 steers)[1]

	Mean	SD	Minimum	Maximum
MMWT, kg	74.70	6.34	58	92
ADG, kg	1.13	0.29	0.4	1.98
DMI, kg	9.18	1.57	4.83	14.28
RFI	0.00	0.83	-3.10	2.72
MPRC	-0.17	1.37	-3.93	3.53

[1]MMWT = metabolic mid-weight
ADG = average daily gain
DMI = dry matter intake
RFI = residual feed intake
MPRC = model predicted residual consumption

Table 3. Family means for efficiency traits[1]

Sire	Family	MMWT	ADG	DMI	MPRC
297J	70	34.1[ab]	0.51[ab]	4.49[a]	0.49
	71	35.1[a]	0.51[ab]	4.20[ab]	-0.23
	95	35.3[a]	0.53[a]	4.39[a]	-0.09
432H	72	32.6[c]	0.45[ab]	3.93[ab]	0.09
	73	32.6[abc]	0.47[ab]	4.27[ab]	0.67
	82	34.0[ab]	0.47[ab]	4.24[ab]	0.43
	96	35.4[a]	0.53[a]	4.53[a]	0.24
437J	74	31.8[abc]	0.39[ab]	4.17[ab]	1.20
	75	32.7[bc]	0.52[ab]	4.39[ab]	0.33
	81	34.5[a]	0.53[a]	4.41[a]	0.13
	83	35.0[a]	0.48[ab]	4.42[ab]	0.63
	97	34.5[a]	0.51[ab]	4.29[ab]	0.08
551G	76	30.3[c]	0.44[ab]	3.76[ab]	-0.05
	77	34.6[a]	0.52[a]	4.35[ab]	0.04
	80	32.8[bc]	0.45[ab]	3.75[b]	-0.28
	84	31.6[c]	0.40[b]	3.56[b]	-0.09
	98	33.7[ab]	0.53[ab]	4.32[ab]	0.04
Avg SE		0.65	0.04	0.26	0.25
Min SE		0.40	0.03	0.21	0.15
Max SE		1.22	0.06	0.40	0.46

[1]MMWT = metabolic mid-weight

ADG = average daily gain

DMI = dry matter intake

MPRC = model predicted residual consumption

[a-c]Within a column: means that do not share a common superscript differ after Bonferroni correction for multiple comparisons ($P < 0.000325$).

Differences among families for metabolic mid-weight, ADG, and DMI are shown in Table 3. Although family was a significant effect ($P < 0.05$) in analysis of MPRC, there were no significant differences after correction for multiple comparisons. Family was not an influential component ($P = 0.14$) of RFI in these data. Families sired by 297J had higher values for metabolic mid-weight, ADG, and DMI. The other 3 bulls sired at least one family with a significantly lower metabolic mid-weight. Differences in ADG and DMI mostly involved families sired by 551G, especially family 84, which had lower ($P < 0.0003$) ADG than 4 other families, 1 each from each sire (including another from 551G). Families 80 and 84 (sired by 551G) had lower ($P < 0.0003$) DMI than 4 families that were sired by the other 3 bulls. Family differences, in the absence of modeled genetic effects, could be indicative of the genetic variation in such traits; previously family effects were noted as large for this experimental population, especially for udder traits (Tolleson et al., 2017) and carcass traits (Riley et al., 2019), but to a lesser degree for other traits.

3.2 Correlations Involving RFI and MPRC

The traits of this study were in many cases strongly related to each other. There were large positive associations of DMI with MPRC and RFI, and low positive associations between metabolic mid-weight with ADG and MPRC, as indicated by the unadjusted correlation coefficients presented in Table 4. As expected, residual correlations of ADG and DMI with RFI were not different from 0. However, correlations (residual and simple) for MPRC with ADG were negative.

Table 4. Simple (above diagonal) and residual (below diagonal) correlation coefficients of efficiency traits[1, 2, 3]

	MMWT	ADG	DMI	MPRC	RFI
MMWT		**0.22**	**0.54**	**0.11**	0
ADG	**0.54**		**0.52**	**-0.48**	0
DMI	**0.66**	**0.76**		**0.47**	**0.53**
MPRC	**0.11**	-0.08	**0.56**		**0.61**
RFI	0	0	**0.57**	**0.96**	

[1]MMWT = metabolic mid-weight
ADG = average daily gain
DMI = dry matter intake
RFI = residual feed intake
MPRC = model predicted residual consumption
[2]Coefficients in bold-faced font differ from 0 (*P* < 0.05).
[3]Residuals were from models that included steer age as a fixed linear covariate, contemporary group as a fixed effect, and animal as a random effect.

Residual feed intake and MPRC have the same base calculation, (observed DMI minus predicted DMI), but they differ regarding how the predicted DMI value is estimated. For RFI, the predicted value is based on a regression of data collected from a given cohort, while for MPRC the predicted value is based on observed performance using a standard model. Considering the similarity in how the two measurements are calculated it is not surprising that analysis revealed a strong positive correlation coefficient of MPRC and RFI. The two measures also had a significant Spearman's rank correlation coefficient (0.62) indicating that steers should rank similarly for MPRC and RFI. This relationship is seen in the Nellore-Angus steers in this study. When comparing RFI vs. MPRC classification within contemporary groups relative to animals that were 1.5 SD away from the mean as low and high (as opposed to the commonly used 0.5 SD), 319 of the steers' rank categories were the same, however 30 differed. This indicates that the average contemporary group value could have major effects on its own efficiency group ranking.

The important difference between MPRC and RFI is the ability to more readily compare across contemporary groups/cohorts. Residual feed intake is dependent upon those contemporary groupings. To illustrate RFI's dependency on the contemporary group an animal is in, an overall RFI (pooled RFI) was calculated and compared to the steer's contemporary group RFI (group RFI). Comparison revealed no animals pooled RFI value matched its group RFI value. Shifting from a negative group RFI value to a positive pooled value did not occur, however 37 animals that had a positive group RFI value had a negative pooled RFI value. Thirty-three steers had over a 2-fold change in RFI from group to pooled. Group classification was compared to pooled classification as well, revealing 53 steers were reclassified. When the same comparison was done with group MPRC classification and pooled MPRC classification, 70 steers had different classifications between the two, the MPRC value itself however, did not change.

Table 5. Simple (first row within an efficiency trait) and residual (second row) correlation coefficients with temperament traits of yearling steers[1, 2, 3]

Trait	Aggressiveness	Nervousness	Flightiness	Gregariousness	Overall
MMWT	0.03	**-0.22**	**-0.19**	**-0.21**	**-0.20**
	0.01	**-0.16**	**-0.11**	**-0.15**	**-0.16**
ADG	-0.09	**-0.14**	**-0.14**	-0.02	**-0.17**
	-0.02	-0.09	-0.10	**-0.13**	**-0.16**
DMI	-0.01	**-0.16**	**-0.15**	-0.08	**-0.19**
	0.03	-0.10	-0.08	-0.12	-0.09
MPRC	0.08	0.02	0.02	-0.02	0.01
	0.07	-0.01	0.01	0	0.08
RFI	0.02	0.05	0.04	0.05	0.1
	0.04	0.03	0.03	0.03	0.09

[1]Coefficients in bold-faced font differed from 0 (*P* < 0.05).
[2]Residuals for efficiency traits were from models that included steer age as a fixed linear covariate, contemporary group as a fixed effect, and animal as a random effect.
[3]Residuals for temperament traits from models of Riley et al. (2016). Those traits scored on a 1-to-9 scale

included aggressiveness—the willingness of the animal to hit an evaluator; nervousness—visual indications to include trembling, vocalization, and other activities (urination, etc.); flightiness—indicated by running, jumping, or climbing behavior; gregariousness—willingness and comfort associated with being isolated from other animals; and overall temperament— distinct evaluator assessment based upon all information observed.

Table 5 provides correlations between efficiency traits and temperament scores. Similar to other reports, we saw slightly negative correlations between steer temperament and metabolic mid-weight, ADG, and DMI. Both simple and residual correlations involving temperament with MPRC and with RFI were not significant.

3.3 Genome-wide Associations

Table 6 provides genes with suggestive associations with DMI. Although a strict control of FDR = 0.05 produced no detected associations of genomic regions with ADG, RFI, or MPRC, a more relaxed control of FDR (0.17) resulted in associations with DMI that included a single SNP on BTA 9 and 4 SNP in a region of BTA 11 (67.1 to 75.7 Mb).

Table 6. Genomic markers with suggestive association (P = 0.17) with daily dry matter intake (DMI) and closest genes

BTA	Mb	Name	Candidate gene	Boundary
9	1.29	ARS BFGL NGS 115046	SPARC related modular calcium binding 2 (*SMOC2*)	within
11	67.11	Hapmap30504 BTA 126653	rho GTPase activating protein 25 (*ARHGAP25*)	within
11	69.84	BTA 28849 no rs	Yippee-like 5 (*YPEL5*)	69.70
11	72.64	Hapmap29423 BTA 126740	microtubule associated protein RP/EB family member 3 (*MAPRE3*)	within
11	75.69	ARS BFGL NGS 12720	kelch like family member 29 (*KLHL29*)	75.62

[1]BTA = *Bos taurus* autosome; Mb = megabase location UMD-3.1 bovine assembly.

[2]Boundary indicates the Mb location of the nearest gene boundary to the marker. Entry in this column of “within” means that the marker was located within the published gene boundaries.

The SNP on BTA 9 with suggestive association with DMI was located within the gene SPARC related modular calcium binding 2 (*SMOC2*; Vannahme, Gösling, Paulsson, Maurer, & Hartmann, 2003), which is a regulator of cell-matrix interactions (Maier, Paulsson, & Hartmann, 2008). The protein product of this gene has been demonstrated to be involved in differentiation in a variety of tissues and structures in mammals, including lung (Wilk, Herbert, Shoemaker, Gottlieb, & Karamohamed, 2007), blood vessels (Rocnik, Liu, Sato, Walsh, & Vaziri, 2006), teeth (AlFawaz et al., 2013; Kim et al., 2016), endometrium (Araujo et al., 2017), cardiac tissue (in which it was differentially methylated; Laugier et al., 2017), kidney, (Gerarduzzi et al., 2017), eye (Al-Dabbagh et al., 2017), cartilage (Wilson et al., 2016), cranial structure in dogs (Marchant et al., 2017), and brain tissue (Roy et al., 2013).

The region located from 67 to 76 Mb on BTA 11 had 4 SNP with suggestive association with DMI. Two of those were within genes, rho GTPase activating protein 25 (*ARHGAP25*; Csépányi-Kömi et al., 2012) and microtubule associated protein RP/EB family member 3 *(MAPRE3)*. The former (*ARHGAP25*) has a regulatory role in neutrophil phagocytosis (Csépányi-Kömi, Sirokmány, Geiszt, & Ligeti, 2012) as well as in mobilization of hematopoietic stem and progenitor cells (Wang et al., 2016). The protein produced by *MAPRE3* is an end binding protein and consistent with its name is involved in the assembly of basic molecular structures (Su & Qi, 2001; Komarova et al., 2009). This gene (*MAPRE3*) was differentially expressed in lymphatic ileal tissue of scrapie infested lambs relative to controls (Austbø et al., 2008), and levels of its protein were elevated in mice olfactory bulbs with respect to a particular odor (Li et al., 2010). Another SNP with suggestive association in this region was near Yippee-like 5 (*YPEL5*) that has documented roles with cell division processes (Hosono et al., 2010). The last of these 4 SNP was near kelch like family member 29 (*KLHL29*, Jin et al., 2017).

4. Discussion

4.1 Relationships Involving Efficiency Traits

The residual correlation coefficients in Table 4 confirm the strong positive relationship of DMI with RFI and with MPRC. These are not genetic correlations, but it is reasonable to think that those would also be large and positive, similar to those reported in Nellore cattle by Matos Ceacero et al. (2016) and in *Bos taurus* crossbred cattle by Rolfe et al. (2011). This relationship suggests that selection for reduced RFI would also reduce breeding values for DMI, which may be detrimental for growing steers on *ad libitum* feed, but would almost certainly be undesirable for their half-sisters as they become producing cows (C. A. Ferrell, personal communication). Decreased DMI could lead to energy and protein requirement deficiencies, and in turn decreased cow and offspring productivity (Funston, Summers, & Roberts, 2012). If satiety in grazing cattle is related to maintenance requirement, then reduced DMI might be indicative of reduced maintenance requirements (manifested as improved efficiency if intake were fixed). It seems appropriate to avoid any management or selection program that could potentially reduce the feed intake (and/or appetite) of beef cows grazing marginal and/or climate-variable resources. If DMI reduction is voluntary and is accompanied by lowered nutritional requirements without reduced production, this could improve production efficiency. Cusack et al. (2021) stated in their sustainability review of global beef production that no one type or breed of cattle showed clear advantages globally; however, the adaptation aspect and production levels of low RFI cattle when utilized in more challenging and variable environments need to be investigated before the most useful strategies can be determined, especially to aid in poverty reduction.

Reclassification of animals when comparing the smaller contemporary groups to the overall group is not surprising; the key difference between MPRC and RFI is that the MPRC value remains stable across comparison because it is based upon a single reference population. Residual feed intake however is a less stable value because it is dependent on the population in consideration (contemporary vs overall in this study). The stability of the MPRC measurement may be advantageous for doing comparisons across different groups, studies, and populations, and, potentially across highly variable production environments.

Based on these results, there appear to be very limited opportunities to use these efficiency traits as predictor traits for beef traits later in the value chain, or vice versa in similar *Bos indicus* crossbred. Although there were some significant correlation coefficients (estimated using either unadjusted trait values or residuals from appropriate models) of these traits with temperament scores (Riley et al., 2016), most were not large (Table 5). This suggests that temperament was not strongly associated with such traits in this population, and this was consistent with reported low genetic correlations of similar traits with flight speed as a temperament trait (Rolfe et al., 2011). However, many researchers have reported strong associations of good temperament with good performance in growing cattle (e.g., Nkrumah et al., 2007; Café et al., 2011). There were strong positive correlations between DMI, ADG, and RFI with traits such as carcass weight and ribeye area, but otherwise these efficiency traits were weakly correlated ($|r| < 0.2$) with quality traits, sensory panel palatability assessments, and panel assessed flavor and aromatics measured on steaks or carcass sides with or without electrical stimulation (data not shown).

4.2 Genome-wide Associations

There have been many genome-wide association studies of efficiency traits in many cattle populations. Several have reported associations of regions of BTA 11 with DMI or RFI (Márquez, Enns, Grosz, Alexander, & MacNeil, 2009; Sherman, Nkrumah, Li, Bartusiak, Murdoch, & Moore, 2009; Bolormaa et al., 2011; Lu et al., 2013; Seabury et al., 2017). Rolf et al. (2012) reported loci associated with average feed intake in Angus cattle on BTA 11 very near the suggestive loci from the present study (78.3 Mb) as well as an association of a locus on BTA 9 (105.9 Mb) with RFI. Abo-Ismail et al. (2018) developed a custom panel of SNP for use with feed efficiency trait improvement. They considered 3 SNP loci on BTA 9 (Rolf et al., 2012; Abo-Ismail et al., 2014) and 10 loci on BTA 11 (Rolf et al., 2012; Yao et al., 2013; Abo-Ismail et al., 2014). Three loci of the 10 loci from BTA 11 were included in that panel (4.7, 3.6, and 28.8 Mb). Genome-wide association studies of these traits in Nellore cattle have reported no DMI or RFI associations on BTA 9 or 11 (de Oliveira et al., 2014; Santana et al., 2014) and associations on both chromosomes with DMI (Olivieri et al., 2016). There has been noted minimal across-population overlap of detected SNP with association for these traits (Saatchi et al., 2014). New methods have been developed to look at multiple feed efficiency GWAS studies to identify similarities. Pathway based meta-analysis, using 201 significant SNP markers from 10 different studies, identified a significant pathway related to residual feed intake: valine leucine and isoleucine degradation. That significant pathway included 3 markers, from 3 different genes, that could be important to residual feed intake (Duarte et al., 2019). Other approaches, such as system biology approaches, may be beneficial to identifying genes that influence feed efficiency (Alexandre et al., 2019).

5. Conclusion

Evaluation of feed efficiency traits such as DMI, RFI, and MPRC in these Nellore-Angus steers revealed family differences for ADG and DMI, but not for MPRC or RFI. Although RFI and MPRC had similar correlations with DMI, MPRC had substantial negative correlation with ADG and slightly positive correlation with weight, whereas RFI will have 0 correlation with these traits by its calculation. The significant correlations between feed efficiency and temperament evaluations seen here were weak, suggesting that temperament differences were not associated with performance traits evaluated in this population. Correlation between RFI and MPRC was 0.61. Use of MPRC as a standardized metric should be investigated relative to RFI because it may facilitate improved across-cohort comparisons and may be useful across diverse production settings as it is computed from a stable reference population, and does not fluctuate between cohort groups. Genome-wide analysis revealed no associations with ADG, RFI, or MPRC, but 5 SNPs were associated with DMI adding to the growing list of SNPs associated with feed efficiency traits. Because MPRC was correlated with both DMI (positively) and ADG (negatively) it is likely more closely associated with economic indicators of production efficiency, but these same benefits may present selection issues similar to the use of RFI. Further use of MPRC may facilitate improved comparisons across studies, and its evaluation across diverse production environments is encouraged.

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Declaration of Interest

The authors declare that there are no conflicts of interest.

Ethics statement

All procedures were in compliance with the Guide for the Care and Use of Agricultural Animals in Research and Teaching (FASS, 2010) and approved by the Texas A&M University Animal Care and Use Committee

Software and data repository resources

The authors declare that the data of this research are not deposited in any official repository.

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Sustainable Agroforestry Crop Rotation System for the Tropics: A Theoretical Exposition

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Abstract

Population pressure is the key reason that has been reducing the duration of fallow in shifting cultivation. In many places, it has changed to bush fallow and subsequently is going towards the need to use available arable lands continuously. As a result, soil productivity is declining since long fallow is required for its regeneration after land is planted for a few years. An agroforestry tree crop/arable crop rotation system was proposed to mimic the natural fallow system and improve nutrient recycling through litter drops, which will improve soil organic matter. As soil organic matter improves the soil structure in addition to the ability of the soil to retain nutrients and water, the land becomes suitable for continuous crop production with appropriate fertilization regimes. The proposed tree crop/arable crop rotation will therefore result in continuous generation of income from harvestable produce in the rotation system year in year out. The paper, equally elucidated on other benefits of rotating tree crops with arable crops on the same land towards achieving maximum land productivity and obtaining benefits from the land without subjecting the land to the traditional fallowing system. This intervention will reduce abject poverty (SDG1), reduce acute hunger (SDG2), promote sustainable economic activities and growth, increase employment and decent work (SDG8) and promote sustainable industrialization and foster innovation (SDG9). The paper also identified the challenges associated with this type of rotation system and proffered suggestions on how to ameliorate such challenges.

Keywords: agroforestry, crop-rotation, litter-drops, soil-productivity, economic-returns, improved-employment

1. Introduction

Crop cultivation is as old as human civilization. In the early times, a farmer would usually cultivate a piece of land until the land's productivity significantly declined, then the farmer leaves that land for another mature fertile forest land to satisfy his/her food needs.

The science behind the progressive decline in soil fertility of farmland under cropping is routed in four main phenomena: that crops take up nutrients as they grow, clearing of vegetative covers opens up the land to increased nutrient leaching, and increased soil erosion with rains. Equally, the burning of the debris after the fallow, converts the slow releasable nutrients in the mulch into soluble nutrients that are more easily leached or eroded away. These phenomena are more pronounced in the high rainfall areas of the humid tropics with highly acidic and leached soil conditions (Tibbits 2017; Gichuru and Kang 1989).

The high human reproductive rate in Sub-Saharan Africa is further compounding the need for continuously increasing the cropping season/phase of their shifting cultivation system before the temporary land abandonment phases. In addition to this major problem, land ownership in these African communities are highly fragmented and does not lean itself to large-scale cropping, mechanization, or permanent tree cropping programmes (Bassey, 2003).

This paper will conceptualize how we can explore and attempt to mimic the attributes of tree crop vegetation to achieve continuous harvesting of economic products from our lands (year in year out) i.e. continuously get economic returns from agricultural lands both during the arable crop farming season/phase and the tree fallow season as a continuous cropping agroforestry system. The beauty of the tree crop/arable crop rotation system is that just like in the shifting cultivation system, harvests are made by the farmers during the arable cropping phase as produce are harvested for food and income. In addition, fruits are harvested during the tree cropping phase, mainly for income while little or nothing is harvested from the land during fallow of the shifting cultivation system. The other point to note is that the enormity of the harvestable quantity of fruits during the tree cropping phase serves as enough incentive for stakeholders to undertake value addition ventures to increase shelf-life of the produce from the tree crops. This eventually will usher in industrialization in the place if well implemented.

If we can successfully conceptualize an agroforestry system or systems that can achieve these lofty ideals, then the communities that adopt such will gain in many ways: improved economic returns, increase in agro-related economic activities including attracting opportunities for stakeholders wanting to establish industries in such places, improvement in employment opportunities among others, and such an attractive system will sell itself easily for adoption by many stakeholders (communities, companies, and governments). This intervention if properly implemented has the potentials therefore to: reduce the proportion of people in abject poverty (SDG1), reduce the number of people that are suffering acute hunger (SDG2), promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all (SDG8) and build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation (SDG9), United Nations Report (2022). In this paper, we shall elucidate on the benefits of rotating tree crops with arable crops on the same land towards achieving continuous cropping and obtaining benefits from the land without subjecting the land to the traditional fallowing system in its true sense. We shall also identify the challenges associated with this rotation system and proffer suggestions on how to ameliorate such challenges.

2. Shifting Cultivation

Shifting cultivation is a traditional land-use system that is a major source of livelihood and sustenance for many people in the third world. It involves clearing relatively matured forest, allowing the cut debris to dry up and then burnt to enable the land to become suitable for arable crop farming. It is noteworthy that burning fallow debris is counter-productive in the effort to ensure nutrient retention since a good portion of nutrients like those of organic nitrogen etc. are converted to mobile or gaseous nitrates and are more easily lost through emission or leaching. Also bush burning destroys soil organisms, soil structure and causes a host of other harmful effects (Tibbits, 2017). The land is usually farmed for two to three years then the farmer moves to another land to repeat the process all over again (Parkey and Shourov, 2020; Punitha et al., 2018).

Putri et al. (2019) carried out a study to identify the population pressure on certain land carrying capacities and to identify the correlation between land pressure and food sufficiency in West Kalimantan. They posited that population growth does not only affect pressure on agricultural land but the land is taken up for the construction of settlements and related amenities. Virgin forests are also cut down to satisfy timber and other needs. They further explained that population increase caused shifting cultivation changes towards continuous cultivation of available land spaces.

Verma et al. (2017) listed 4 strategies that can be applied to improve shifting cultivation: fallow management, integrated farming system, multi-storey agroforestry and watershed management.

3. Problems of Population Pressure and Land Use

As the human population continues to increase, the available land per individual progressively decreased. While the population of Nigeria was only 37.1 million people in 1950, the population has increased in 2020 to 206.1 million people (Worldometer, 2022; CEIC Data, 2022). At the same time, the land space of Nigeria over the same years span remained at 910,770 km^2. The clear logic of the above information is that the population of the country has increased more than five times within 70 years but the land space remained constant. Though this is true, the population density changes differ from region to region and the pressure is higher in the southern parts of Nigeria and in the bigger cities of the nation (World Bank, 2022; Worldometer, 2022). Lawrence (2018) used the following words to explain what was happening *"Nigerian population is increasing and our resource base and economy are stagnant or are deteriorating. … Overpopulation affects every aspect of our national life. The Forest ecosystems suffer because we cannot end firewood harvesting in most of Nigeria, as there is population pressure and there are no feasible alternatives… We have a rapidly growing population and Nigeria for example, may become the third most populated nation on earth within the next 40 years with the current growth rate."*

This phenomenon of population pressure implies that the luxury of abandoning land to rest and regenerate its crop productive support systems after farming it for some time is gradually becoming a luxury that is no longer feasible. The traditional cropping phase of about two or three years before fallowing began to suffer pressure from the need to prolong the number of years before temporary land abandonment to meet the increasing need of feeding the increasing population.

4. Some Strategies to Ameliorate the Situation

4.1 Soil Fertility Issues and Manuring

Nature restores soil fertility after cropped land has been fallowed for some years as the land is re-vegetated first by grasses, then shrubby weeds, and finally forest trees. Soils in the humid tropics are relatively poor in nutrients and are acidic. These conditions necessitate the need for appropriate fertilizer and/or manure application. I will elucidate more on the importance of improving soil fertility through manure application in this section.

Trees play a major role in soil fertility regeneration as the deep roots of the trees take up leached-down nutrients and return them to the topsoil when the leaves drop off the trees as litter and are decomposed in the natural ecosystem. Apart from that, the litters when decomposed become stable organic manure in the soil improving the humus content of the soil.

Demand for arable land will keep increasing as the population keeps increasing correspondingly because the length of time to keep land fallow will inevitably have to keep reducing. It is for this reason, the peasantry continuously reduced the fallow length and subsequently shifting cultivation changed to bush fallow system but as can be noted, that was a temporary solution since the population increases continued. It is, therefore, necessary to evolve a system that will ensure continuous economic returns to the poor farmers through continuous cultivations of the land. International Institute of Tropical Agriculture with stations in Ibadan and Port Harcourt over some decades spent time and resources trying to resolve this problem. They conducted several types of research in alley cropping using suitable local fallow/arable crops combinations (IITA 2011). However, one of the setbacks of the alley-cropping system they evolved is that the economic returns during the fallow seasons were negligible which may be only firewood or yam stakes as harvestable products after the fallow. The major benefit of the alley cropping system they evolved was improved organic manure content of the soil which increased soil fertility with the improved fallow litter droppings during the short fallow and through pruning and mulching during crop cultivation phases. The other objectives included the possibility of using some of the pruning from the alley cropping to provide fodder for small ruminants. The primary purpose of alley cropping in this regard is to produce organic mulch in-situ and in so doing provide its benefits to the crop component. Organic mulching is the placement of plant material on soil for purpose of enhancing crop production. Cutting down plants or pruning the branches and leaves is a good way of mulching in an artificial way catalyzes and boosts the natural nutrient recycling processes. The literature is replete with publications on how mulching improves soil nutrients including nitrogen, calcium, potassium, soil structure through aggregate formation, nutrient retentive abilities with increased Cation Exchange Capacity (CEC) and improved soil ability to reduce water evaporation, etc. (Lal et al., 1975; Hahn et al., 1979; Gichuru, 1990; Gichuru and Kang, 1989; Lawrence, 1993).

Lawrence et al. (1993) also suggested three ways of producing organic matter: Alley cropping as explained earlier, rotation fallow with legumes, etc. and finally producing mulch on separate land. This last method of producing mulch on separate land is more tedious and is only suitable for small-scale farming including that of backyard farming and garden agriculture.

4.2 The Principles of Crop Rotation

Alhameid et al. (2017) defined crop rotation by Martin et al. (1976) as "*a system of growing different kinds of crops in recurrent succession on the same land*".

Crop rotation helps in controlling soil disease build-up, insect pest build-up, etc. as it helps in starving off the build-up of such crop pests and diseases which are adapted to the particular crop but not the succeeding crop in the sequence.

Further improving on the benefits of crop rotation, Magdoff and Harold (2000) listed some principles to guide crop rotation, ranging from legume fallowing, not following related crops with each other and following with crops that will leave enough residue.

While it will be difficult to introduce crop rotation in perennial systems, agroforestry can help modify perennial systems using either alley cropping and rotating the intercrops within the alleys.

4.3 Tree Crop/Arable Crop Rotation System

During fallow, the natural vegetation regrows and eventually trees grow as the vegetation matures. Therefore deliberately growing trees after the arable cropping cycle will enhance soil regeneration. However, growing economically beneficial tree crops to the farmer as fallow crop means that while the soil is fallowing the farmer is making some harvests that have economic benefits. We do know that there will be nutrient losses along with the harvest of fruits during the tree crop growing phase. So, in the technical sense, soil fertility may not improve since some produce harvesting will result in nutrient depletion. The implication is that soil fertilizers are needed during the fallow cropping phase as well as during the arable cropping phase in the rotation sequence being proposed. At the same time, the other aspect of fallowing is the accumulation of litter drops (decaying of leaves that drop to the ground). The litter drops improve the soil texture and also improve nutrient retention in the soil with increasing soil manure content. Both accumulations of nutrients and organic matter are critical for soil productivity after fallow. Growing suitable tree crops with suitable fertilizer regime applications can enhance continuous and sustainable cultivation of agricultural lands in the tropics. This otherwise would not have been possible without the tree crop and arable crop rotation systems as proposed. It is known that initially, it takes time for tree crop establishment, so the tree seedlings are inter-cropped with arable crops until the tree canopies begin to overshadow the intercrop. At that time, the trees are allowed to grow as mono-crop for a while as their fruits are harvested for income. Then after a while, the trees are pruned down to allow for the arable crop rotation phase for maximal component contribution in the rotation system. Depending on the coppicing abilities of the tree crop, they can be pruned down reasonably to reduce competition for nutrients and light. Also, occasional pruning is encouraged not only to reduce shading of the intercrop but also to continually introduce organic mulch for the continuous productivity of the soil and nutrient supply to the intercropped or arable component in the rotation.

5. The New Concept towards Continuous Cultivation

5.1 Possible Crop Combinations

This concept is suitable for many regions of the world. The type of tree crop to be used will depend on the region. For example, at the fringes of the rain forest or in the savannah forest lands of Nigeria the use of tree crops like the Cashew plant (*Anacardium Occidentale*) is suitable. In the rainforest region of Nigeria, possible tree components can be the Cocoa plant (*Theobroma Cacao*), Rubber plant (*Hevea Brasiliensis*), Mango plant (*Mangifera Indica*) among others. After growing arable crops as is the normal tradition for some years and when productivity begins to decline then, the land can be grown to one of the economic trees mimicking the natural fallow system. As explained, fertilizations will be required during all the phases to complement the natural regeneration process.

5.2 Sequencing and Timing of Rotation

5.2.1 Possible Tree Crop/Arable Crop Rotations

I shall give some possible rotation cycles that a farmer can choose for this system. All the proposals assume that the land is relatively large enough for the commercial growth of economic trees. And the land will be divided into portions to ensure the rotations are effective and the optimum benefits of the tree crop components are not compromised, also the sequence gives the farmers adequate time to properly utilize the land in phases, learning as the phases progress and bringing in modifications where necessary.

Rotation 1: Land is divided into 5 portions. At the start of the programme, only one-fifth of the land is grown to the desired tree crop. Depending on the sequence (especially with regards to the ultimate age of the tree before the tree crop will be cut down to give room for the arable crop rotation phase), it is developed. For example, if the ultimate age of the tree crop for this sequence is determined to be 20 years, then for a 5 portioned rotation land, the first portion will be planted in year 1, the next portion will be planted after 5 years of planting of the first portion and the third portion will be planted after 10 years of the planting of the first portion and 5 years of planting of the second portion, this sequence of 5 years interval will continue until all the 5 portions are planted as shown in Table 1 below. It follows that by the time the 5th portion is planted, the first portion is already 20 years old and is due to be cut down and grown to the arable crop. Subsequently every 5 years, the arable cropping will move to the next land that has been grown to tree crop for 20 years and the cycle continues in perpetuity.

Depending on the type of tree crop and the type of micro rotation that is planned for the portion for the arable crop, the age of the mature tree crop is determined to know when the tree is pruned or cut down and so also will be the age of rotation. Arable crop rotation phase can last between 3 to 5 years depending on the micro arable crop regime implemented and the types of the arable crop planted. While ultimate age of maturity before cutting down of the tree crop can range from 9 to 20 years depending on the biological information on when fruit production begins to decline or when the opportunity cost of maintaining the tree crop is no longer as favourable.

5.2.2 A Possible Tree Crop/Arable Crop Rotation Sequence for Continuous Land Utilization Scheme

Table 1. A sequence of tree crop of maximum 20 years before cutting down to grow arable crops for 5 years in a land divided into 5 portions

	PLOT SECTION 1	PLOT SECTION 2	PLOT SECTION 3	PLOT SECTION 4	PLOT SECTION 5
Year 1	Start growing tree crop	Grow other crops	Grow other crops	Grow other crops	Grow other crops
Year 5	Tree crop grown is 5 years old	Start growing tree crop	Grow other crops	Grow other crops	Grow other crops
Year 10	Tree crop grown is 10 years old	Tree crop grown is 5 years old	Start growing tree crop	Grow other crops	Grow other crops
Year 15	Tree crop grown is 15 years old	Tree crop grown is 10 years old	Tree crop grown is 5 years old	Start growing tree crop	Grow other crops tree crop
Year 20	Tree crop grown is 20 years old. **Cut tree crop down and grow an arable crop**	Tree crop grown is 15 years old	Tree crop grown is 10 years old	Tree crop grown is 5 years old	Start growing tree crop
Year 25	Start growing tree crop	Tree crop grown is 20 years old. **Cut tree crop down and grow an arable crop**	Tree crop grown is 15 years old	Tree crop grown is 10 years old	Tree crop grown is 5 years old
Year 30	Tree crop grown is 5 years old	Start growing tree crop	Tree crop grown is 20 years old. **Cut tree crop down and grow an arable crop**	Tree crop grown is 15 years old	Tree crop grown is 10 years old

Table 1 above explains a two-rotation sequence of unequal crop component lengths. While the tree crop is grown for 20 years, the arable cropland is cultivated for 5 years. However, the land is divided into 5 parts with 4 parts at every time grown to the tree crop. That follows that by the time the land is fully used up 80% of available land is under tree crop cultivation at any particular time. However, each of the 5 land portions is maturing at different times in line with the planting sequence and the arable crop cultivation is therefore rotating at a 5-year interval.

The above is for a sequence of 5 years interval. If however the interval is shortened to, for example, 3 years instead of 5 years, the tree crops will have a maximum age of 12 years before they are cut down to grow arable crops for 3 years in a land divided into 5 portions sequence as above.

Table 2. A sequence of tree crop of maximum 15 years before cutting down to grow arable crops for 5 years in a land divided into 4 portions sequence

	PLOT SECTION 1	PLOT SECTION 2	PLOT SECTION 3	PLOT SECTION 4
Year 1	Start growing tree crop	Grow other crops	Grow other crops	Grow other crops
Year 5	Tree crop grown is 5 years old	Start growing tree crop	Grow other crops	Grow other crops
Year 10	Tree crop grown is 10 years old	Tree crop grown is 5 years old	Start growing tree crop	Grow other crops
Year 15	Tree crop grown is 15 years old. **Cut tree crop down and grow an arable crop**	Tree crop grown is 10 years old	Tree crop grown is 5 years old	Start growing tree crop
Year 20	Start growing tree crop	Tree crop grown is 15 years old. **Cut tree crop down and grow an arable crop**	Tree crop grown is 10 years old	Tree crop grown is 5 years old
Year 25	Tree crop grown is 5 years old	Start growing tree crop	Tree crop grown is 15 years old. **Cut tree crop down and grow an arable crop**	Tree crop grown is 10 years old
Year 30	Tree crop grown is 10 years old	Tree crop grown is 5 years old	Start growing tree crop	Tree crop grown is 15 years old. **Cut tree crop down and grow an arable crop**

Table 2 above explains a two rotation sequence of unequal crop component lengths. While the tree crop is grown for 15 years, the land for arable crops is cultivated for 5 years. However, the land is divided into 4 parts with 3 parts at every time grown to the tree crop. That follows that 75% of available land is under tree crop cultivation at any particular time.

Similarly as in Table 1 if the sequence duration is shorten to 3 years then the tree crops will have a maximum of 9 years before they are cut down to grow arable crops for 3 years in a land divided into 4 portions.

5.3 Possible Challenges

5.3.1 Fertilization Issues

For optimum returns from both the tree crop and arable crop components, an appropriate fertilization regime must be developed for use during the cropping phases of both components. The fertilization practice to be adopted for the arable component will depend on what is cropped. For example, the intercropping of cassava with maize or yam with maize will require different fertilization from cultivating pineapple, banana/plantain. Pineapple, banana/plantain, and normal garden crops will do much better with the application of animal manure fertilization together with inorganic fertilizers to grow such crops beyond 3 years effectively and continuously on the same piece of land. It follows that having poultry production for example to generate manure in the farm or having access to such manure in sufficient quantity elsewhere can help sustain sustainable production of the crops for upwards of 5 years and beyond as proposed in the sequence.

With the litter production during the tree cultivation phase and possible pruning of the trees during the arable crop cultivation phases, there will be adequate organic matter produced to stabilize the soil condition for continuous large-scale cropping.

5.3.2 Coppicing versus Replanting

Most fruit trees coppice easily. That means they easily regrow bringing out new shoots if they are cut down at a good height so long as it is not at the root level. This particular attribute is important if a tree crop has to be used as a component in this type of rotation cycle. Cocoa, Rubber, Mango, Cashew trees all coppice well. However, a tree cropping phase that had lasted for more than 15-20 years before the cropping of arable crops on that same piece of land can as well be replanted altogether for any agronomic or other compelling scientific reasons after the older crop had been growing for so many years.

Depending on the intentions of the farmer, the tree crops can be pruned during the arable crop phase to reduce shadow and introduce organic mulch for the arable crops.

5.3.3 Removal of Tree Roots (Stumping) during Arable Crop Phase

Rooting up (stumping) can be an expensive operation for those using mechanization to prepare the land during the establishment of the arable crops after the tree cropping phase. Though this might not be a challenge for those using zero or minimum tillage system as a practice, adequate provisions for mechanized land preparation is required for large scale crop farming.

5.4 Role of Government

Traditionally, the government’s role is to identify the development needs of the people and then point stakeholders towards such directions. To do this, the government applies several strategies: tax incentives, provision of land at attractive rates for projects, provision of other amenities like electricity, roads, etc. At other times, the government starts a pilot scheme or takes up the implementation of the projects. However, it is well known that governments or generally publics/communities are usually unable to manage income-generating or commercial ventures because of the selfish influence of the non-owning managers or the influence of political meddling with pure commercial decisions. In addition, often to keep their jobs in public-owned corporate organizations, projects managers often try to please many supervisors who have powers to get them sacked. While a project owner, who had invested a lot of capital into the business, will see the growth of the business as a priority, a supervisor who is not a business owner but prone to corruption may see what will benefit him in the business as a competing priority to the continued and fast growth of the business. That means that such a supervisor may exert pressure on the project manager to take along his self-interest with the goal of making a profit. A project manager may therefore have conflicting needs of pleasing the supervisor along with making maximum profit. Such influences imply that the project managers have to make subjective decisions to please such bosses instead of taking the best-unbiased decisions in the interest of the business. These tendencies exist in government and other publicly owned businesses. It is for that reason controls are always critical to the survival of publicly commercial businesses. The establishment of corruption-proof policy guidelines and the use of a good management information system along with regular performance assessment reviews will help ensure business profitability. A more long-term strategy will be for the government to divest the majority of its shares in the business to both the public and a management consultant who will also have shares in the business. Such Public-Private Partnerships (PPP) have greater chances of becoming sustainable and profitable. Another reason why government involvement is needed at least at the initial stages is to encourage large crop plantations or the establishment of large-scale industries because of the complicated process of acquiring large contiguous land from numerous units of people. Government is more able with the current land use law in the constitution of

Nigeria to ensure such large parcels of land can be acquired successfully. Also, many private entrepreneurs are not willing to take the initial risks of investing huge capital in a business. They would, however, like to come in after the businesses have been established to participate in the profit-making and sharing of dividends.

Many state governments in Nigeria had economic crop plantations some decades ago which by implication are commercial ventures. However, agricultural production as the mainstay of the national and sub-national economies took the back seat when crude oil production and sales became the most prominent source of revenue for the Nigerian nation. Many agricultural plantations were neglected or abandoned as a result. In Rivers State, for example, rubber plantations were established, and they are occupying more than 10,000 hectares of land and were at peak production some decades ago (Iroegbu et al., 2021; Abolagba et al., 2016). Those expanses of land can be used for this programme to enhance agricultural and economic productivity. Also about a decade ago, the government was to start a partnership with some private entities as consultants to cultivate about 5,000 hectares of land for Cocoa That project had been suspended. With this new concept, that project can be revived in line with this proposal and that would lift the state as a major producer of Cocoa and would generate a lot of income for the government and other shareholders. The large acreage of land under the rubber plantations that were established in the same state several decades ago can be revived or the land can be converted to grow better revenue-generating crops. A holistic approach where this crop rotation system is encouraged and also post-harvest value-adding industries established can improve the economy of all the stakeholders. Entrepreneurs can go into that adding value aspect to these crops and improve the market availability to encourage the increased cultivation of the crops. Apart from making effort to add value to the product before they are marketed internally and externally, Cocoa has high market value and there is an export market in Europe, America, and even Asia (FAO, 2021).

Many partnership opportunities exist with other nations. The United States of America had announced a possible partnership in the past with Cashew farmers including those in Nigeria https://www.thecable.ng/nigeria-to-benefit-from-60m-prosper-cashew-project/amp. This also applies to many other export opportunities with many crops from Nigeria and beyond.

6. More Research Needed

Research will be required to identify suitable tree crops that can be used in this rotation system. Some possible economic crops like Cocoa, Rubber, Cashew, and Mango can be assessed towards identifying their suitability as good candidates from the agronomic and economic perspectives. The growing of these crops as individual crops permanently is fairly known but for the proposed system, they will be cut down after several years to give room for arable crop planting. The cutting down of these crops will generate massive litter and mulching materials during the arable crop cultivation phase. Research is needed on the best ways of mulching and adequacy fertilizer application that will equally be required. The ways of coppicing and frequency need to be studied, so too is the need to understand the various agronomic/economic returns using the different tree crop/arable crop rotation durations.

7. Conclusion

This paper had explained the benefits of tree crop/ arable crop rotation. I have stated that this system improves soil fertility through tree crop cultivation that builds up organic matter, which invariably increases nutrients and better soil structure. I have also established in the paper that these attributes improve soil productivity.

Usually, shifting cultivation involves cultivating land for about 3 years and leaving it to fallow for not less than 5 years. Percentage utilization of the land is therefore less than 38%. No income is derived from the land during fallow. Prolonging the cropping duration will mean poor yield so no net economic benefits. If soil productivity is improved by this tree crop/arable crop system then land utilization is increased to nearly 100% hence derived income too to the farmer is improved. This tree crop/arable crop rotation system therefore ensures greater income for all stakeholders.

The massive cultivation of economic tree crops and that of arable crops requires that the system is accompanied by post-harvest value-adding facilities to reduce post-harvest losses. That means the introduction of new facilities either for storage or increasing the shelf lives of the produce. Apart from the large-scale production which will need a lot of sub-contractors, suppliers, and other services for the smooth running of the businesses; others will provide direct and indirect services needed by employers of the business. There will be many retailers, many people requiring accommodation, transportation, catering, and many other services. The location of the business will have a large influx of people and the accompanied increased economic activities will bring more income to the people.

As stated above, every large-scale business generates much direct employment and also many indirect employment opportunities. The post-harvest facilities and subsequently the industries that should be established to process the raw materials of this business will equally generate a lot of employment. For example, a massive Cocoa farm should generate the need for farmhands, those to tend the plants, those to harvest the fruits, and those to dry the seeds before transportation to market or industries. There will be national gains too as industries far detached like the airlines will all benefit from the export business that will ensue.

Government has a major role to play to bring this model into mass implementation and adoption.

Every region should work out what tree crops it wishes to specialize in and plan how to set up ready market and industries to take up the produce. That way, even smallholder farmers may wish to grow these crops since they are assured of a ready market when they make the harvest.

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Development of Drip Flow Technique Hydroponic in Growing Cucumber

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Abstract

Hydroponics is a new branch and aspect of food crop growing that in recent years made its mark in developing country such as Nigeria. Although, its adoption has not been too encouraging. This research work aimed at developing a drip technique system of hydroponics in determination of the agronomic parameters of cucumber by comparing the yield, water and nutrient efficiency, its consumptive use and proximate and mineral composition of cucumber. The experiment was carried out in a complete randomized design with three treatments; organic substrate (coconut coir), inorganic substrate (styrofoam) and soil. These treatments were replicated five times. The vegetative growth (agronomic parameters), yield, water and nutrient, proximate and mineral composition were measured. The result showed the consumptive use as 0.0044 m^3 per day and 0.3212 m^3 as the water and nutrient use efficiency. The result also showed that organic substrate gave the highest mean plant height of 736.66 mm, highest mean stem diameter of 5.79 mm and highest mean number of leaves of 9.75 while inorganic substrate gave highest mean plant height, mean stem diameter and mean number of leaves as 336.28 mm, 4.95 mm and 7.68 respectively. Also, the highest result of control (soil) gave 301.23 mm, 5.47 mm and 7.06 for the mean plant height, stem diameter and number of leaves respectively. The yield of cucumber as compared with the different growing media showed that there is no significant difference between the growing media ($F_{crit>}$ F_{cal}) unless for the plant height and number of flowers having F_{crit} less than F_{cal}. From these results, it is advisable that drip technique system should be embraced by farmers whose primary aim of farming is for leafy vegetables and non-leafy vegetables as seen in the increase in stem diameter and plant height in the organic substrate.

Keywords: drip-flow, hydroponic, cucumber, yield, consumptive use, quality

1. Introduction

Hydroponic being a new science in engineering and agriculture refers to the technique of growing plants using nutrient solution with or without the use of growing medium such as gravel, vermiculite, rockwool, peat moss, saw dust, coir dust, coconut fibre, etc. to provide mechanical support for the root. Hydroponics as a term was derived from the Greek words *hydro'* meaning water and *ponos'* means labor which can be literally refers to as water work (Olubanjo & Alade, 2018). While some hydroponic systems operate automatically to control the amount of water, nutrients and photoperiod based on the requirements of different plants, others operate manually by changing the nutrients periodically especially when it is too acidic or basic. Due to rapid urbanization and industrialization not only the cultivable land is decreasing but also conventional agricultural practices causing a wide range of negative impacts on the environment (Kadianska, 2016). To meet year 2030 sustainable agenda of United Nations goals of zero hunger, methods for growing sufficient food have to evolve. Modification in growth medium is an alternative for sustainable production and to conserve fast depleting land and available water resources. Soilless cultivation might be considered as another alternative for growing healthy food plants, crops or vegetables, etc. (Butler & Oebker, 2006).

Agriculture without soil entails hydro-agriculture (Hydroponics), aqua-agriculture (aquaponics) and aerobic-agriculture (Aeroponics) as well as substrate culture. Various commercial and specialty crops can be grown using hydroponics including leafy vegetables, tomatoes, cucumbers, peppers, strawberries, and many more. Worldwide arable land is already less than 0.2 ha per capital at present and is expected to further shrink to

0.15 in 2050. Urbanization and industrialization has also led to a drastic decrease in per capita water availability, cultivable land and also greater decrease in conventional agricultural practices causing a wide range of negative impacts on the environment in Nigeria. To sustainably feed the world's growing population, new methods of growing sufficient food crop need to be developed (Benedito, Kotcon, & Fess, 2011). Some outdoor crops are faced with problems such as continuous soil degradation, loss of fertility, indiscriminate chemical inputs use, and above all continuous depletion of water resources of which there is a way to strike a balance in the combination of water, nutrients, and oxygen which the plant needs in order to maximize yield and quality. These problems can be managed by developing a controlled environment, regulating nutrients rate for plants, securing the farmland and so on. This will invariably maximize agricultural productivity and reduce/eradicate undue financial losses and everyone will be adequately and nutritiously fed without over exploiting the natural resources.

Hydroponics has been adapted to many situations, from outdoor field culture and indoor greenhouse culture to grow vegetables and fruits (Sharma, Acharya, Kumar, Singh, & Chaurisia, 2019).The cucumber most likely originated in India (south foot of the Himalayas), or possibly Burma, where the plant is extremely variable both vegetative and in fruit characters. It has been in cultivation for at least 3000 years. The cucumber (*Cucumis sativus* L.) belongs to the Cucurbitaceae family, one of the more important plant families. Cucumber (Cucumis sativus L.) is an edible cucurbit popular throughout the world for its crisp texture and taste. Cucumbers are often eaten as a vegetable but they are scientifically considered a fruit as they contain enclosed seeds and develop from a flower (AnamWaheed, 2017). The high water content makes cucumbers a diuretic and it also has a cleansing action within the body by removing accumulated pockets of old waste material and chemical toxins. Cucumbers help eliminate uric acid which is beneficial for those who have arthritis, and its fiber-rich skin and high levels of potassium and magnesium helps regulate blood pressure and help promote nutrient functions. The magnesium content in cucumbers also relaxes nerves and muscles. However, this crop has not much been considered for cultivation under drip flow hydroponic system in Nigeria. The aim of this research work is to determine the growth, yield rate, proximate, mineral composition and consumptive use of cucumber plant using drip flow system of hydroponic to produce the fruit.

2. Materials and Methods

2.1 Study Areas

The experiment was carried out at Agricultural and Environmental Engineering experimental farm plot of the Federal University of Technology, Akure, Ondo State, Nigeria (7.2995^{0}N, 5.1471^{0}E). (Figure 1) As a tropical area, Akure has a high temperature throughout the year. The average daily temperature is 26 °C with a range between 18^{o}C and 35^{o}C. Mean annual relative humidity of about 80% andrelief is about 396 m above sea level (Odubanjo, Olufayo, & Oguntunde, 2011).

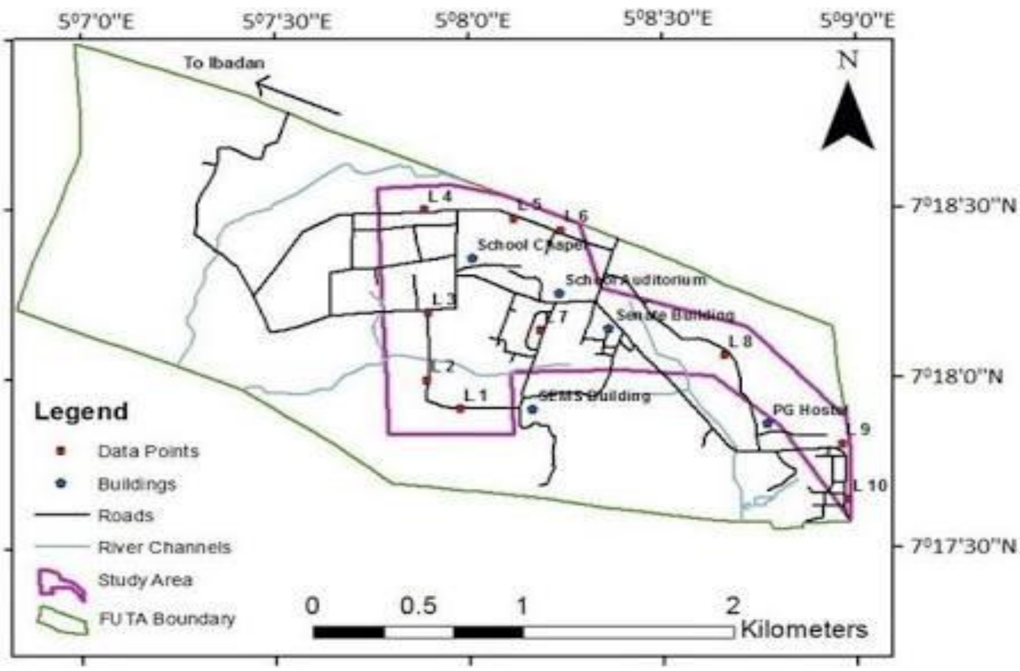
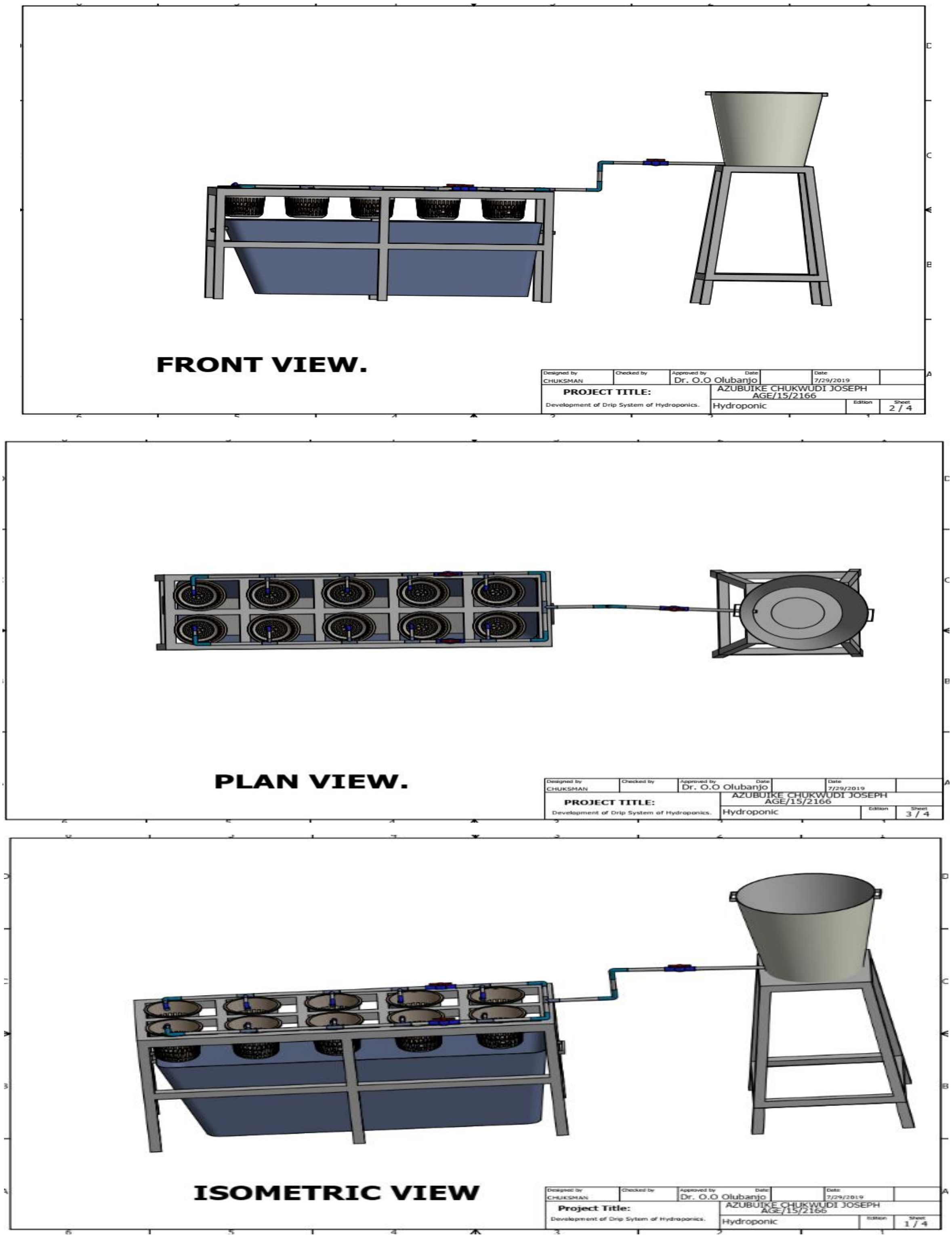


Figure 1. Map of the Study Area

2.2 Experimental Unit and Design

The plastic substrates holder in this study was 25cm diameter and 20cm depth. Nursed seedlings was transplanted into the substrate holder on 05th August, 2019 which contains the substrates (coconut coir and styrofoam) between 7:30am and 8:05am. The seed was obtained from International Institute of Tropical Agriculture, Ibadan (IITA). Seedlings were transplanted after two weeks of emergence with the soil be shaken off. The nutrients were mixed. The mixing proportion was according to Mccall & Nakagawa, (1970) and Olubanjo & Alade, (2019). The diagrams in figure 2 explained the design of the experimental units.



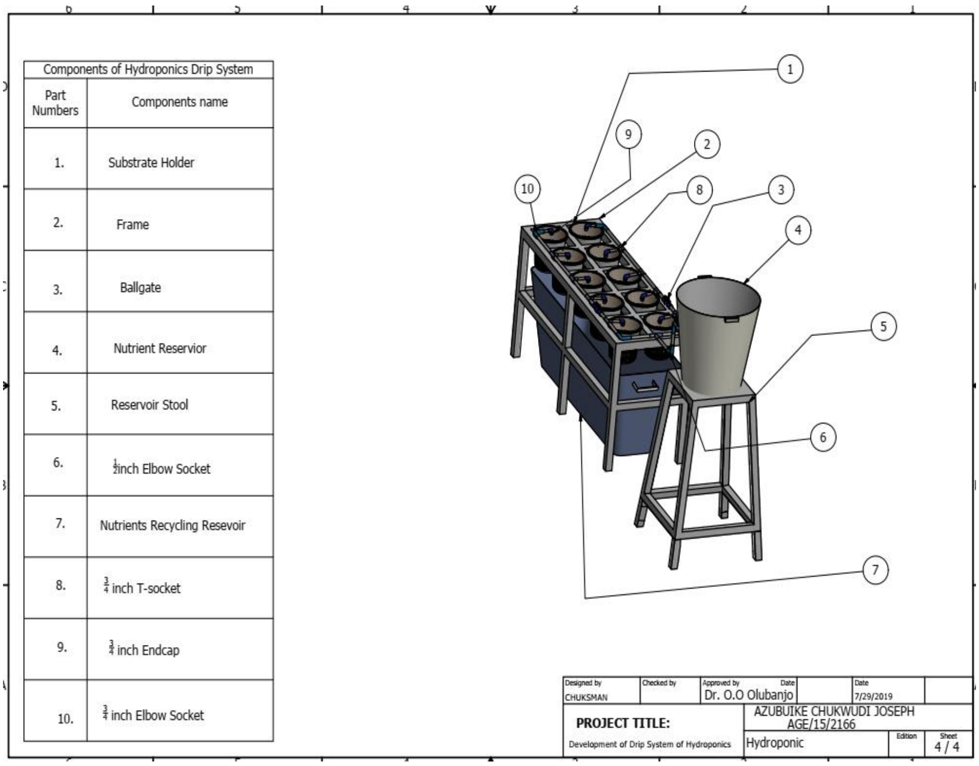


Figure 2. Orthographic and exploded view of the planting unit

3. Results and Discussion

3.1 Elemental Chemical Composition of Coconut Coir

The elemental composition of the substrate was done in the chemistry laboratory of the Federal University of Technology, Akure. Below were the results obtained from the test.

Table 1. Elemental Composition of Coconut Coir

Elements	Composition(Mg/litres)
Calcium (Ca)	5.96
Manganese (Mn)	0.18
Potassium (K)	3.74
Iron (Fe)	0.00BLD
Phosphorus (P)	0.00BLD
Nitrogen (N)	0.28
Protein	1.75

3.2 Agronomic Parameters of Cucumber

Agronomy parameters taken were leaf length, stem diameter, leaf width, number of flowers, plant height and the date. The mean of these values are presented in the table below.

Table 2. Mean Values of Agronomic Parameters from Control Experiment (Soil)

	Mean stem diameter (mm)	Mean leaf length (mm)	Mean leaf width (mm)	Mean number of leaves	Mean plant height (mm)	Mean number of flowers
Plant 1	4.34666667	95.6666667	100.1	5.3333333	204.6	0.9
Plant 2	5.47166667	125.333333	130.8666667	7.06666667	301.2333333	1.166667
Plant 3	4.21333333	110.6666667	120.5666667	7.06666667	295.0333333	1.3
Plant 4	4.14333333	83.63333333	85.66666667	5.56666667	173.4	0.9333333
Plant 5	4.43166667	103.0333333	109.1333334	5.66666667	186.8666667	1.0666667

Table 3. Mean Values Agronomic Parameters from Organic Substrate (Coconut Coir)

	Mean stem diameter (mm)	**Mean leaf length (mm)**	**Mean leaf width (mm)**	**Mean number of leaves**	**Mean plant height (mm)**	**Mean number of flowers**
Plant 1	4.05862069	117.1034483	123.6551724	8.13793103	407.655172	1.965517241
Plant 2	4.27931035	90	94.72413793	5.37931035	219.448276	1.24137931
Plant 3	5.7862069	137.6206897	141.0689655	9.34482759	574.827586	2.551724138
Plant 4	5.57586207	148.6206897	150.4827586	9.75862069	736.655172	2.172413793
Plant 5	4.56206897	130.3448276	139.8275862	8.20689655	374.62069	1.620689655

Table 4. Mean Values of Agronomic Parameters from Inorganic Substrate (Styrofoam)

	Mean stem diameter (mm)	**Mean leaf length (mm)**	**Mean leaf width (mm)**	**Mean number of leaves**	**Mean plant height (mm)**	**Mean number of flowers**
Plant 1	4.28793103	93.2068966	101.862069	5.75862069	262.3448276	0.5862069
Plant 2	4.9724138	144.37931	151.965517	7.482758621	297.2068966	1.1379310
Plant 3	4.0948276	91.5517241	97.3448276	4.689655172	126.4827586	0.9310345
Plant 4	4.6258621	123.62069	125.827586	7.689655172	336.2758621	1.7241379
Plant 5	3.9611111	77.0740741	79.259259	5.296296296	124.8518519	0.8076923

Table 5. Comparison between the Mean Stem Diameter for Control Experiment, Organic Substrate and Inorganic Substrate

	Mean stem diameter for control (mm)	**Mean stem diameter for organic substrate (mm)**	**Mean stem diameter for inorganic substrate (mm)**
Plant 1	4.346666667	4.05862069	4.287931034
Plant 2	5.471666667	4.279310345	4.972413793
Plant 3	4.213333333	5.786206897	4.094827586
Plant 4	4.143333333	5.575862069	4.625862069
Plant 5	4.431666667	4.562068966	3.96111111

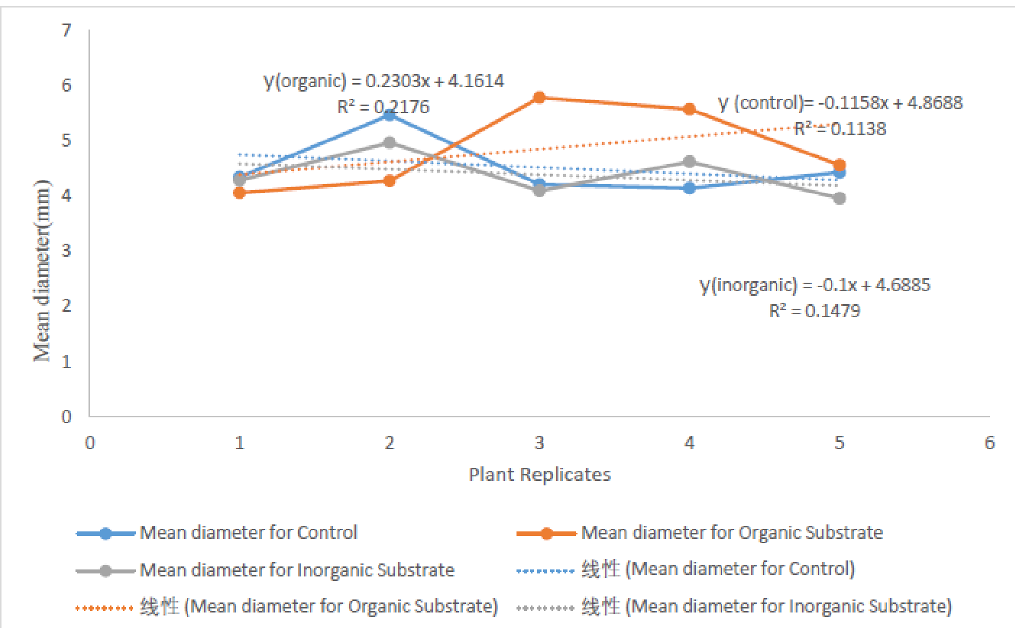


Figure 3. Graph showing relationship between the treatments stem diameters (mm)

Table 6. Analysis of variance (Anova) table showing relationship between the treatments and stem diameters (mm)

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Mean diameter for Control	5	22.60667	4.521333	0.294858		
Mean diameter for Organic Substrate	5	24.26207	4.852414	0.609551		
Mean diameter for Inorganic Substrate	5	21.94215	4.388429	0.169079		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.570933	2	0.285466	0.797773	0.472833	3.885294
Within Groups	4.293947	12	0.357829			
Total	4.86488	14				

Anova: Single Factor

The result from Figure3 shows that cucumber stem is enhanced in organic substrate than other substrate media used in the experiment. This result is seen in the value of R^2 (i.e. 0.2176) which is greater than the R^2 in the inorganic and control experiment which is 0.1479 and 0.1138 respectively. These conform with the result of Eifediyi & Remison (2010).

Also, from the value of $F_{calculated}$ and $F_{critical}$ in the Anova table shown in table 6, it showed that there is no significant difference between the stem diameters of the substrate media having $F_{calculated}$ as 0.7977 and $F_{critical}$ as 3.885. These results agreed with the findings of Olaniyi & Fagbayide (1999); Olaniyi, Akanbi, Adejumo, & Akande (2010); Olubanjo & Alade (2019).

Table 7. Comparison between the Mean Leaf Length for Control Experiment, Organic substrate and Inorganic substrate

	Mean leaf length for control (mm)	**Mean leaf length for organic substrate (mm)**	**Mean leaf length for inorganic substrate (mm)**
Plant 1	95.6666667	117.1034483	93.20689655
Plant 2	125.333333	90	144.3793103
Plant 3	110.6666667	137.6206897	91.55172414
Plant 4	83.63333333	148.6206897	123.6206897
Plant 5	103.0333333	130.3448276	77.07407407

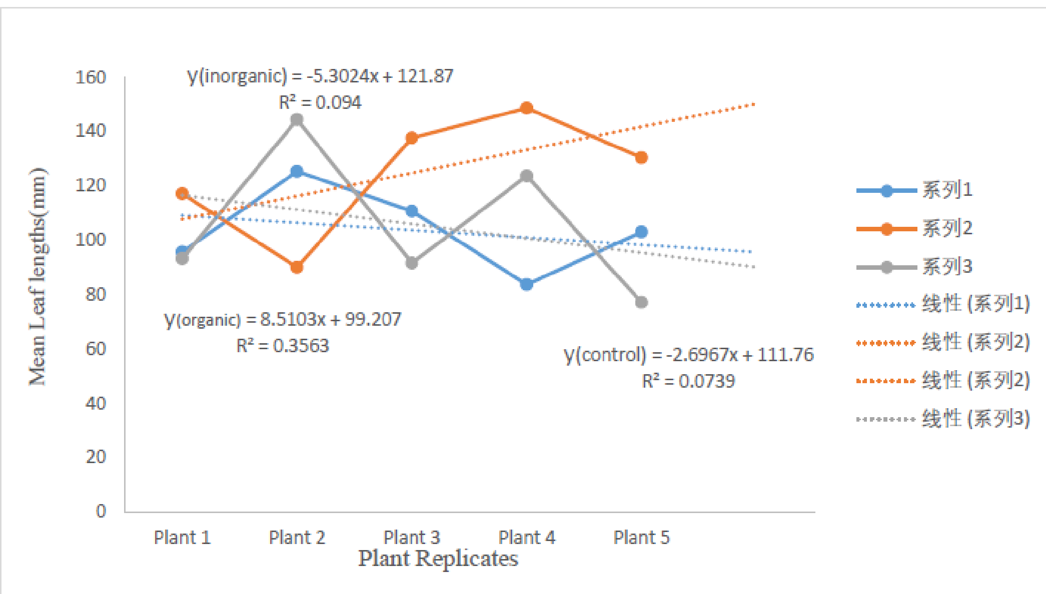


Figure 4. Graph showing relationship between the treatments and leaf lengths (mm)

Table 8. Analysis of variance (Anova) table showing relationship between the treatments and leaf length (mm)

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Mean Leaf Length for Control	5	518.3333	103.6667	246.045		
Mean Leaf Length for Organic Substrate	5	623.6897	124.7379	508.1995		
Mean Leaf Length for Inorganic Substrate	5	529.8327	105.9665	748.145		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1336.088	2	668.044	1.333963	0.29983	3.88529383
Within Groups	6009.558	12	500.7965			
Total	7345.646	14				

The results from the Fig 4 shows that the organic substrate have a greater value for leaf length compare to the other two growing media (inorganic and soil). It has value of R^2 as 0.3563 compare to that of inorganic substrate (i.e. R^2 is 0.094) and control experiment (i.e. R^2 is 0.0739). The yield from the experiment was in agreement with the report of Murwira & Kirchman (1993).

The value of $F_{critical}$ and $F_{calculated}$ as shown in the Anova table (Table 8) shows that there is no significant difference between the leaf length in the growing media. This has been corroborated through 1.3339 and 3.8852 as values for $F_{calculated}$ and $F_{critical}$ respectively. This result agreed with the works of Eifediyi & Remison (2010); Adenawoola & Adejoro (2005) who observed that organic material can improve the growth and yield of cucumber.

Table 9. Comparison between the Mean Leaf Widths for Control Experiment, Organic Substrate and Inorganic Substrate

	Mean leaf width for control (mm)	**Mean leaf width for organic substrate (mm)**	**Mean leaf width for Inorganic substrate (mm)**
Plant 1	100.1	123.6551724	101.862069
Plant 2	130.8666667	94.72413793	151.9655172
Plant 3	120.5666667	141.0689655	97.34482759
Plant 4	85.66666667	150.4827586	125.8275862
Plant 5	109.1333334	139.8275862	79.25925926

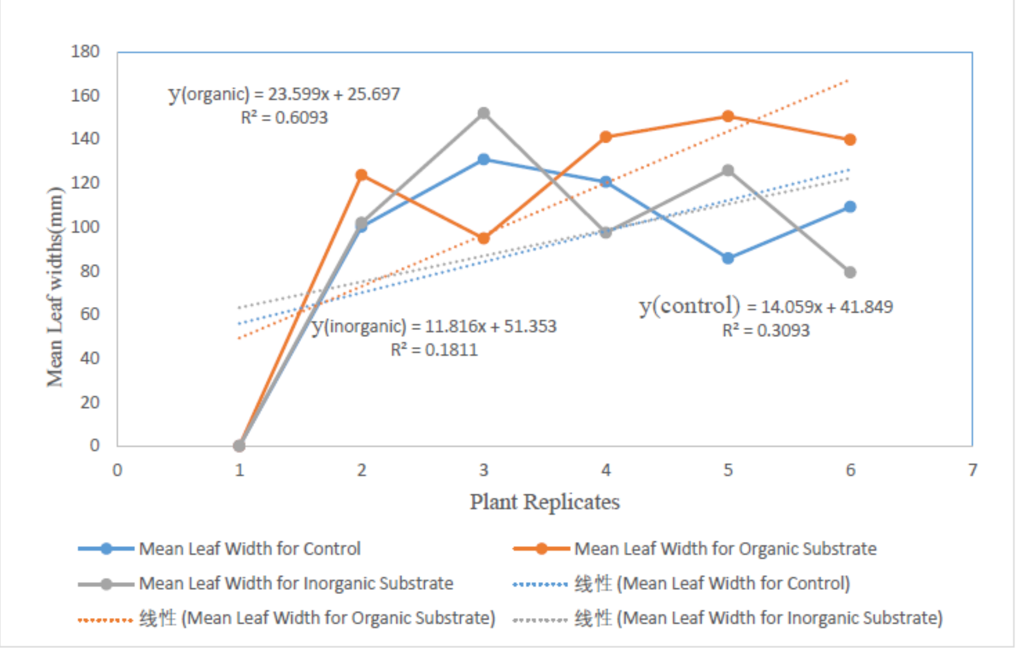


Figure 5. Graph showing relationship between the treatments and leaf widths (mm)

Table 10. Analysis of variance (Anova) table showing relationship between the treatments and leaf widths (mm)

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Mean Leaf Length for Control	5	546.3333	109.2667	308.8139		
Mean Leaf Length for Organic Substrate	5	649.7586	129.9517	480.8196		
Mean Leaf Length for Inorganic Substrate	5	556.2593	111.2519	793.7885		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	1302.496	2	651.2482	1.233875	0.325598	3.885294
Within Groups	6333.688	12	527.8073			
Total	7636.184	14				

The values of R^2 in the graph (Figure5) which are 0.6093, 0.1811 and 0.3093 for organic, inorganic and control experiment respectively show that cucumber have a higher leaf width in organic substrate having greater leaf widths compare to the other two growing media. There is also no significant between the leaf lengths of the substrates media. This has been justified in the Analysis of Variance table (Table 10) with $F_{calculated}$ and $F_{critical}$ as 1.2338 and 3.8885 respectively. This was in agreement with Fuchs, Rauche, & Wicke. (1970) and Ayoola & Adeniyan, (2006) who reported that nutrients from mineral fertilizers enhanced the establishment of crops while those from the mineralization of organic matter promoted yield when manures and fertilizers were combined.

Table 11. Comparison between the mean for number of leaves for control experiment, organic substrate and inorganic substrate

	Mean number of leaves for control	**Mean number of leaves for organic Substrate**	**Mean number of leaves for Inorganic substrate**
Plant 1	5.3333333	8.137931034	5.75862069
Plant 2	7.06666667	5.379310345	7.482758621
Plant 3	7.066666667	9.344827586	4.689655172
Plant 4	5.566666667	9.75862069	7.689655172
Plant 5	5.666666667	8.206896552	5.296296296

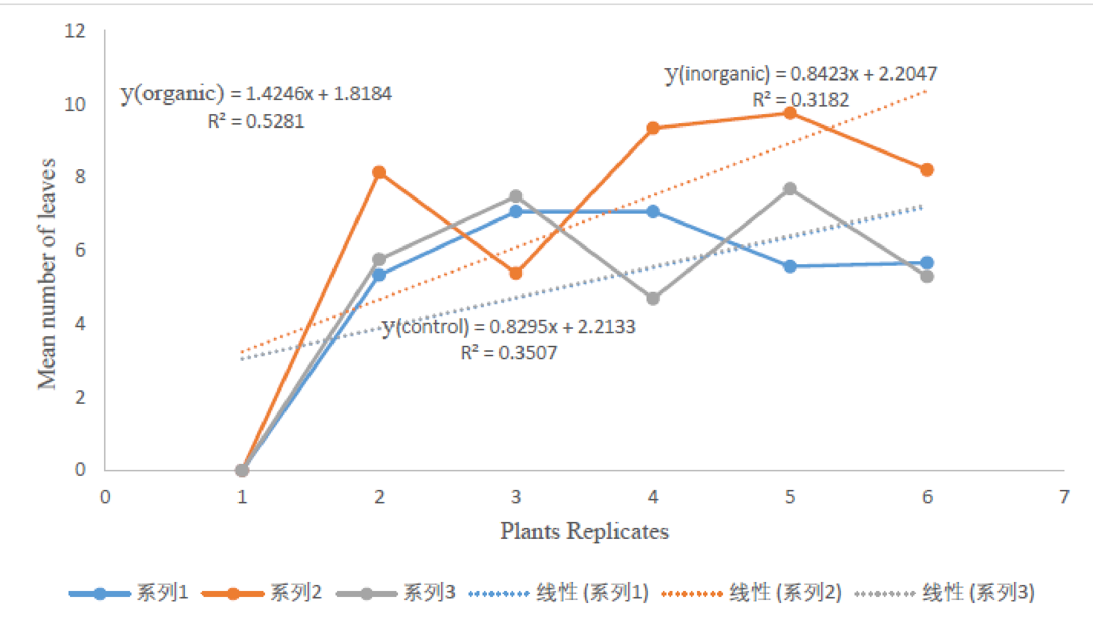


Figure 6. Graph showing relationship between the treatments and number of leaves

Table 12. Analysis of variance (Anova) table showing relationship between the treatmentsand number of leaves

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Mean Number of leaves for Control	5	30.7	6.14	0.730222		
Mean Number of leaves for Organic Substrate	5	40.82759	8.165517	2.923543		
Mean Number of leaves for Inorganic Substrate	5	30.91699	6.183397	1.78895		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	13.38901	2	6.694503	3.689979	0.05636	3.885294
Within Groups	21.77086	12	1.814239			
Total	35.15987	14				

Anova: Single Factor

Organic substrate yielded more leaves. This is seen in Figure 6 with R^2 as 0.5281 compare to 0.31282 and 0.03507 of R^2 for the inorganic and control experiment. This may be due to potential nutrient in the coconut coir. This agrees with the results of Enujeke, (2013). Also, there is little significant difference between the three substrates media having $F_{calculated}$ as 3.6899 and $F_{critical}$ as 3.88529 in the Anova table (Table 12). However, the result was similar to the findings of Majanbu, Ogunlella, & Ahmed(1996) and Ibrahim, Amans, & Abubakar (2000) who reported that genetic constitution of crop varieties influences their growth characters.

Table 13. Comparison between the mean plant heights for control experiment, organic substrate and inorganic substrate

	Mean plant height for control (mm)	**Mean plant height for organic substrate (mm)**	**Mean plant height for inorganic substrate (mm)**
Plant 1	204.6	407.6551724	262.344828
Plant 2	301.2333333	219.4482759	297.206897
Plant 3	295.0333333	574.8275862	126.482759
Plant 4	173.4	736.6551724	336.275862
Plant 5	186.8666667	374.6206897	124.851852

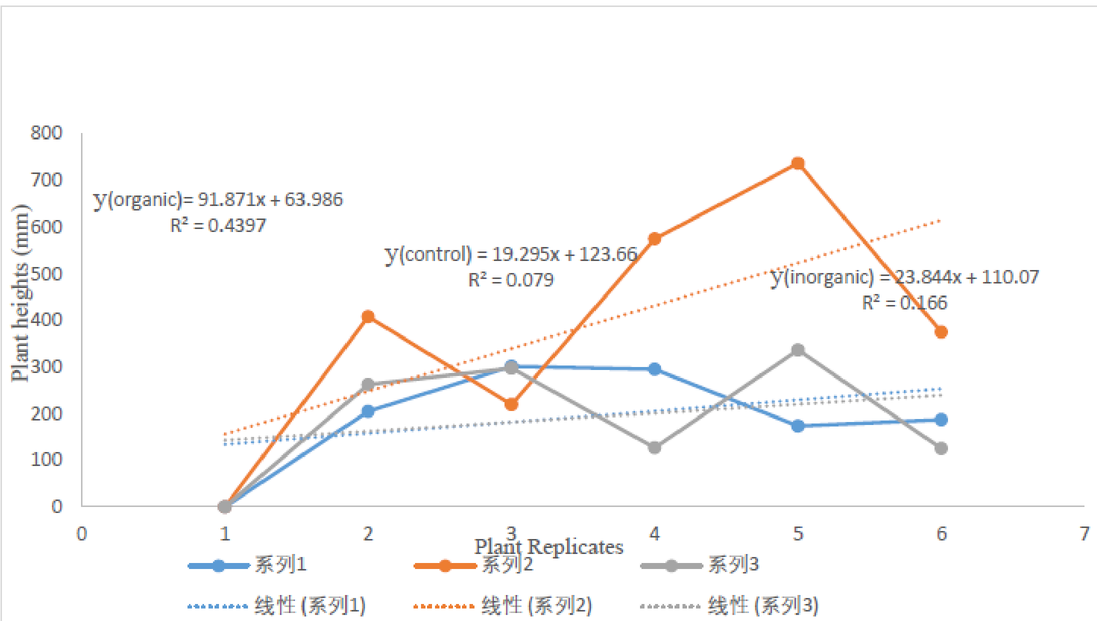


Figure 7. Graph showing relationship between the treatments and plant heights (mm)

Table 14. Analysis of variance (Anova) table showing relationship between the treatmentsand heights (mm)

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Mean Plant height for Control	5	1161.13	232.227	3746.94		
Mean Plant height for Organic Substrate	5	2313.27	462.644	39395.3		
Mean Plant height for Inorganic Substrate	5	1147.12	229.434	9656.94		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	17912	2	89570.6	5.08921	0.0259	3.8853
Within Groups	21119	12	17599.3			
Total	39031	14				

Anova: Single Factor

The growth as regard the height have dwindling form especially for the control (R^2 =0.079) as shown in fig 7. This may be cause by nutrient deficiency in the soil medium or presence of insect pests in soil or inability to trap sunlight for photosynthetic use. In the case of organic medium, the growth was rapid especially for (P5). This increase in height may be as a result of nutrient concentration on the growing medium (coconut coir) or the ease of trapping of nutrients by the root. There is a significant difference between the plant heights which have 5.08928 and 3.8853 as $F_{calculated}$ and $F_{critical}$ respectively. This result agreed with the works of Eifediyi & Remison (2010); Adenawoola & Adejoro (2005) who observed that organic materials can improve the growth and yield of cucumber and was also in agreement with Ayoola, (2010) who reported that nutrients from mineral fertilizers enhanced the establishment of crops while those from the mineralization of organic matter promoted yield when manures and fertilizers were combined.

Table 15. Comparison between the Mean Number of Flowers for Control Experiment, Organic Substrate and Inorganic Substrate

	Mean number of flowers for control	**Mean number of flowers for organic substrate**	**Mean number of flowers for inorganic substrate**
Plant 1	0.9	1.965517241	0.586206897
Plant 2	1.166667	1.24137931	1.137931034
Plant 3	1.3	2.551724138	0.931034483
Plant 4	0.93333333	2.172413793	1.724137931
Plant 5	1.066666667	1.620689655	0.807692308

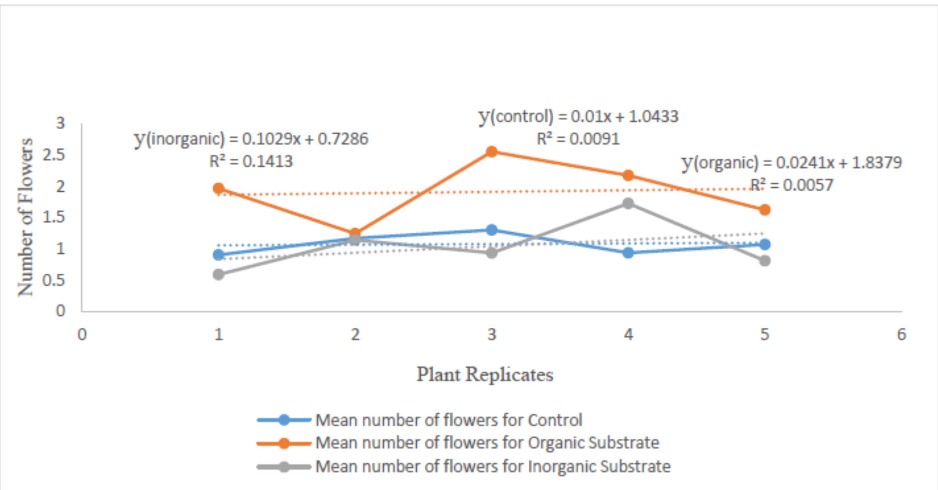


Figure 8. Graph showing relationship between the treatments and number of flowers

Table 16. Analysis of variance (Anova) table showing relationship between the treatments and number of flowers

SUMMARY						
Groups	*Count*	*Sum*	*Average*	*Variance*		
Mean number of flowers for Control	5	5.366667	1.073333	0.027444		
Mean number of flowers for Organic Substrate	5	9.551724	1.910345	0.253627		
Mean number of flowers for Inorganic Substrate	5	5.187003	1.037401	0.187342		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2.439852	2	1.219926	7.813133	0.00672	3.8853
Within Groups	1.873654	12	0.156138			
Total	4.313506	14				

Anova: Single Factor

3.3 Consumptive Use of Water and Nutrients Solution for Cucumber (CU)

The consumptive use of water as seen in the experiment was approximately 4.5 litres (0.0045 m^3). This was seen in the change in nutrient level. The nutrient which was released for the plants at 9:05am on July 07^{th} 2019. This nutrient reservoir gate was locked at same time the following day (July 08^{th}, 2019). It was found that the nutrient used was 0.0045 m^3, after subtracting the volume of the nutrient collected and the one remaining in the reservoir from the total volume of nutrients initially mixed.

Volume of nutrient initially in the reservoir before release (V_1) =30 litres (0.03 m^3)

Volume of nutrient left in the reservoir after locking the valve (V_2) =7.2 litres (0.0072 m^3)

Volume of nutrient that drained from the substrate (V_3) = 18.4 litres (0.0184 m^3)

Volume of nutrient used per day considering both minor and major losses (V_4)

$$V_4 = V_1 - (V_2 + V_3)$$

V_4 = 0.03 - (0.0072 + 0.0184)

V_4 = 0.0044 m^3per day

3.4 Water and Nutrients Use Efficiency (WUE) of Cucumber

The amount of water required by the plant (cucumber) from the day of transplanting (04^{th} August,2019) to the day of harvest (09th October, 2019) was approximately 33 litres of water neglecting any losses either due to pipe material, irrigation accessories used and human factor when recycling the nutrient. This was done by taking the level of nutrient solution in the reservoir every week of the experiment and doing the necessary subtraction. The level of nutrient from the day of release was noted and subsequent drop in volume were taken up to the day harvest. In order to get the flow rate of water, the nutrient solution drop was observed for 48 hours after the day of 1^{st} release.

$$\text{Flowrate (Q)} = \frac{V}{T}(m^3/s)$$

V is volume dropped (m^3), T is time (seconds)

Volume dropped = 2.5 litresi.e (0.0025 m^3)

$$\text{Hence, flowrate} = \frac{0.0025}{48 \times 60 \times 60} = 1.447 \text{ x } 10^{-8}\, m^3/s$$

WUE= CU × number of days for maturity (73days)

WUE= 0. 0044 × 73

WUE= 0.3212 m^3

3.5 Proximate and Nutrients Composition of Cucumber Fruit Obtained from the Different Growing Media (Organic, Inorganic and Control)

The proximate analysis was carried out to determine the percentage of ash content, crude fibre, crude fat and crude protein. This is shown in Table 17.

Table 17. Proximate and nutrients composition of cucumber

Growing media	% Ash content	% Crude fat	% Crude fibre	% Crude Protein
Organic (coconut coir)	16.64	8.27	13.64	0.44
Inorganic (styrofoam)	16.72	6.64	10.52	0.45
Control (soil)	15.79	6.63	12.11	0.47

The result from the proximate and nutrient composition showed that the percentage of ash content range from 15.79% to 16.72%, the crude fat range from 6.63% to 8.27% with organic substrate having the highest percentage. The percentage of crude is between 10.52% to13.64% and that of crude protein is between 0.44% to 0.47%. This shows that cucumber has low protein content. The results for the mineral analysis of organic substrate agrees with Abbey et al., (2017). This may be due to the similarity in environmental condition of the study area or the similarity in soil nutrient composition of Abbey Nwanchoko, & Nkiroma (2017) and nutrient composition of coconut coir in this study. The result of proximate analysis of soil also is in line with Adeyi, (2010) and Makinde & Eyitayo (2019).

4. Conclusion

The experiment has clearly showed that hydroponics system of growing cucumber has greater yield of fruit compare to soil medium. Use of organic substrate yielded more results than other growing media, the results in different table presented in the write up has corroborated this fact, there is greater growth rate (especially in heights of cucumber in hydroponics compare to soil), hence the need for practice hydroponics. Cucumber in drip system of hydroponics also showed that there is conservation of nutrients and water although there may be transmission of diseases which could be from greenhouse surrounding. The proximate and nutrient composition of cucumber was found to be in accordance with the standard nutrient of cucumber.

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Declaration of Interest

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