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Full Length Research Paper

Climate change impact and adaptation pathways for forest dependent livelihood systems in Nigeria

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Climate change is projected to adversely impact rural livelihoods; especially forest communities dependent on climate sensitive natural resources. Communities within five ecological regions (Mangrove, Rainforest, Guinea savanna, Sudan savanna and Montane forest) in Nigeria were assessed using structured questionnaires to gauge the impact of climate change and adaption responses. Households in the Mangrove, Rainforest, Montane forest, Guinea savanna and Sudan savanna derive 47, 34, 31, 19 and 14% of their livelihood from the forest respectively. More than 75% of households surveyed have experienced impacts of climate change on forest resources, except in the Montane forest zone where only 33% were impacted. In the mangrove and rainforest regions impacts were mostly manifest as excessive rainfall, in the montane forest, Sudan and Guinea savanna, impacts were due to reduced rainfall. Adaptation options in the mangrove and rainforest regions were mainly used for forest conservation and to reduce the impact of excessive rains, while in the montane forest, Guinea and Sudan savannas most strategies are aimed to reduce the impact of aridity such as irrigation, mulching, planting deep and the use of shades. Such community based information can provide a foundation to build an organized, systematic and mitigated approach needed for community-centered adaptive mechanism for sustainable forest resource management. Significantly, this can be used to ensure a steady flow of livelihood support services from a range of ecological regions in Nigeria and across the wider West African sub region.

Keywords: Ecosystem, forest management, forest resources, poverty, sustainability

INTRODUCTION

One of the greatest challenges to livelihoods in the 21st century, particularly in developing countries, is the threat from climate change (UNDP, 2010) that could potentially reverse decades of development gains, such as those focused on achieving the Millennium Development Goals. Africa will bear the major import of climate change due to high population growth, reliance on rain fed agriculture, rapid development trajectories, and high levels of poverty and low level of infrastructure.

Since the last ice age, the climate of the earth has been relatively stable, but in recent years average temperature has been increasing. This is associated with climate change. Climate change is a large-scale, long-term shift in the planet's weather patterns or average temperatures (Met Office, 2014). As a result, annual average temperatures are projected to increase between 1.8 and 4.8°C and annual precipitation will change by between –12 and +25% (seasonal changes range from –43 to +38%)

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in Sub-Saharan Africa by 2100 (Muller, 2009). Such a climate shift will impact on ecosystem composition (like the forest) and distribution with ensuing resource scarcity (UNFCCC, 2007), leading to ramified socioeconomic effects on those who depend on such resources for their livelihoods.

Forest dependent people are defined by DFID (2000) as those that use forest as a source of water, fuel wood, shelter and a broad suite of non-timber forest products (medicinal plants, culinary herbs, fodder, rattans, gums, resins, latex and oils). Virtually everybody in the West African region is forest dependent at different scales directly or indirectly on a daily basis. Such common pool resources can contribute substantially to livelihoods, particularly of the rural poor (Jodha, 1995; Cavendish, 1999; Kerapeletswe and Lovett, 2001). Resources derived from forested areas are key components of the natural resource base and fundamental to the socio-economic well-being of any community, region or country (Bann, 1997; Inonio, 2009). This is particularly so in sub-Saharan Africa where most countries have large rural populations that depend directly or indirectly on natural resources and agricultural activities for their livelihoods (Ezeani, 1995). With sustainable management, forests have the capacity to provide a perpetual stream of income and subsistence products, while supporting other economic activities through broader regulatory ecological services and functions (Neumann and Hirsch, 2000; Verweij et al., 2009; Watson and Albon, 2011).

The contribution of forests to sustainable livelihoods cannot be over-emphasized; it is estimated that about 500 million people across the world depend on forest resources for their livelihoods (Roper and Roberts, 1999). Forests provide households with income, fuel wood, food security, reduces vulnerability to shocks and adversities and generally increasing wellbeing (Arnold, 1998; Warner, 2000; Fisher and Shively, 2005; Eva and Fred, 2013). More broadly, forestsare vital for ecosystem and regulatory services, such as water and carbon management (Watson and Albon, 2011). Forest products add important variety, vitamins and increase palatability to main food staples (FAO, 2005). Food products such as roots, tubers, rhizomes and nuts are widely used between meals; eaten while working in fields or herding. In addition to these supplementary roles, forest foods are extensively used to meet dietary shortfalls bridging “hunger periods”, when stored food supplies are dwindling and the next harvest is not available (FAO, 2005). Hence, forest products smooth seasonal peaks and troughs in farm production; a role that is particularly important in periods of floods, droughts, famines and wars.

In Nigeria, for example, over 90% of the rural population depends on agro foresting for livelihoods (Federal Government of Nigeria, 1997; UN, 2002; IMF, 2005; FAO, 2008), deriving over 10% of the Gross Domestic Product from the forest sector (FAO, 2003), thus, underscoring the importance of the forest sector to the socio economic lives of the Nigerians. Against this backdrop, DFID (2009) asserts that climate change could result in between 2 to 11% GDP loss globally by 2020 and from 6% to 30% by 2050; costing an estimated US$ 100 to 460 billion. Given the importance of forest resources, it is paradoxical, that in spite of their current and potential value, how individual respond to climate change is relatively under-researched (Aiyeloja and Ajewole, 2006).

This paper aims at quantifying forest dependence and assessing the impact of climate change on forest resources and captures the ensuing adaptation options adopted by the households to cope with the impacts of climate change in managing their forests resources. Although the study is in Nigeria, results are applicable to the wider West African region due to comparable vegetation and communities.

MATERIALS AND METHODS

Data were collected from 450 rural households, sampled from five broad ecological regions in Nigeria, Figure 1, using a structured questionnaire (Appendix 1), interviews were focused on assessing the socio economic attributes of respondents, types of forest, forest governance, access to forest, forest management, forest resource use, level of dependence on forest resources, forms of climate change impacts (Appendix 2) and adaptation strategies adopted by the households (Appendix 3).

Based on the relative size of the population which they support, and the prevalence of forest cover, 150, 100, 100, 50 and 50 households were sampled from the rainforest, mangrove forest, Guinea savanna, montane forest and Sudan savanna zones respectively. For the rainforest zone the Cross River high forest was chosen as this is the only area of surviving lowland rainforest cover, not just in Nigeria, but across West Africa. Communities were selected from the respective states and research assistants in each of the area who understood the local languages were used for the study. Communities were selected based on information from local informants on their reliance on forest resources. Five communities were selected from each of the rainforest and mangrove forest areas, four from Guinea savanna (Appendix 4), three from montane and two communities were chosen from Sudan savanna ecozone.

Communities were chosen using a random draw from all possible communities in the target areas. In each community households were randomly selected using the communities' roll calls. From the roll call, different households were selected at random intervals until the required number of households per community was reached (this was directly proportional to the total population of the different communities). Structured questionnaires were administered on a one to one basis, with the household heads, or other family members who were familiar with forest resource use by the household and the wider community. To check for interviewer bias and ensure data consistency and compatibility, the addresses and mobile phone numbers of each respondent were collected and information supplied by the interviewer randomly crosschecked in all zones. The data collected were coded and screened for consistency and analyzed using STATA statistical software.

RESULTS

Results are presented in three sections: the first section

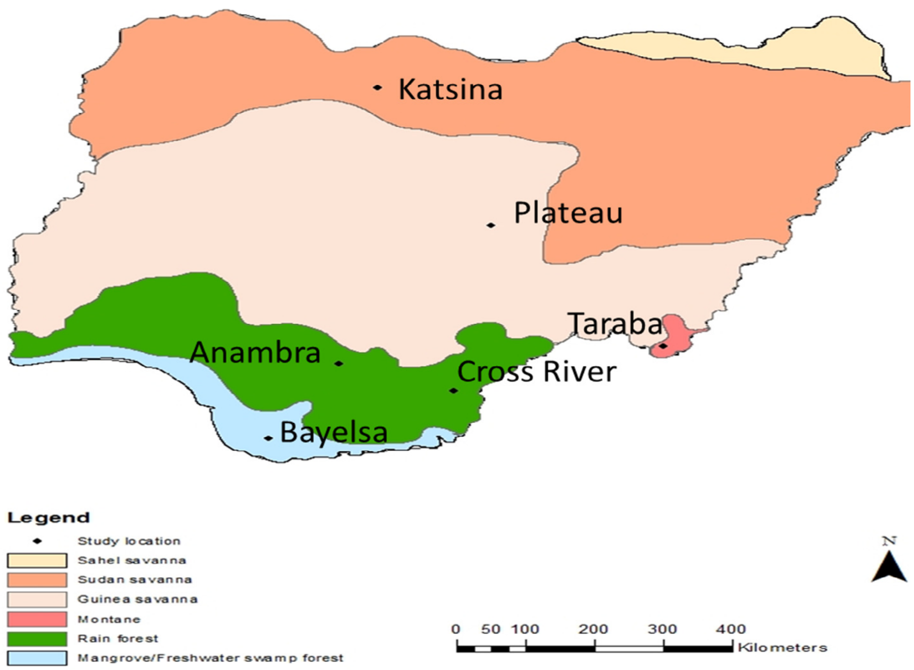

Figure 1. Map of Nigeria; showing areas where the study was carried out.

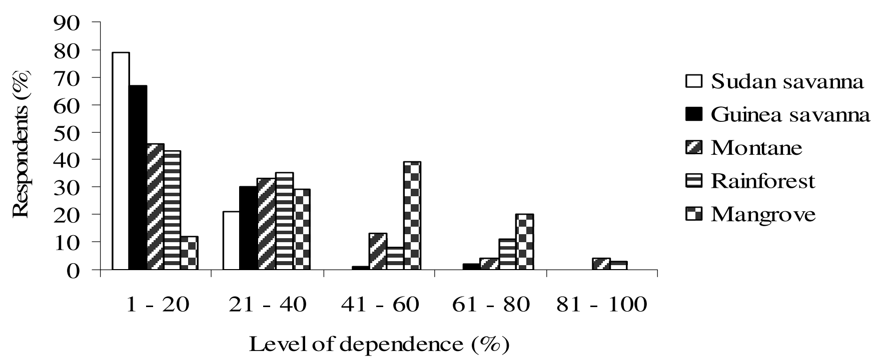

Figure 2. Level of forest dependence across ecological regions.

presents an overview of how forest resources contributes to household livelihoods; the second section assesses how communities perceive climate change impact in their use of forest resources; the third section focuses on the different adaptation options adopted by the households in the face of such climate change impacts across Nigeria.

Forest contributions to livelihood system

Forest resources are important to the livelihoods of the households across Nigeria, Figure 2. Forest resources in the mangrove ecosystem contribute an average of 47% to household income with a range of 10-80%; households depend on both aquatic and terrestrial flora and fauna for food and income. Rainforest communities derive an average of 34% of their livelihoods from the forest with a range of 10-95%. Montane forest contributes an average of 31% to livelihoods with a range of 5-95%. Guinea savanna contributes about 19% with a range of 5-80% (although with a big skew to low dependence), while the Sudan savanna contributes the least, 14%, with a range of 5-30%. On average, forest resources supply about 39% to the livelihoods of rural populations in Nigeria.

Changes in forest resource use and their drivers

Most respondents across ecological zones have experienced changes in their use of the forest resource,

Table 1. Percentage number of respondents experiencing changes in forest resource use due to climate change in the different ecological zones of Nigeria.

Ecological Zone	Change in forest resource (%)
	Yes
Mangrove forest	75
Rainforest	84
Guinea savanna	82
Sudan savanna	94
Montane	33

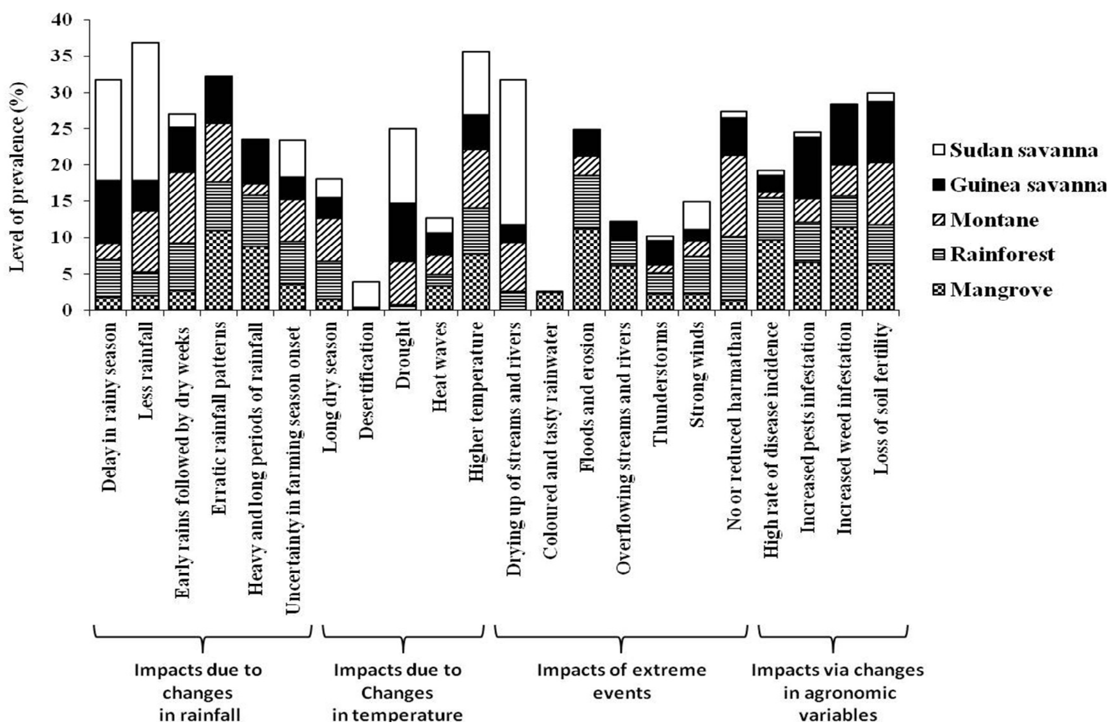

Figure 3. Climate change impacts in the different ecological regions.

Table 1. Perceptions of climate change, and how these impact through forest resource availability and use in the different ecological zones, were determined, Figure 3, and the general consensus was that climate change is predominantly responsible for the changes, Figure 4. In the mangrove ecosystem, some of the key impacts are increased weed infestation, floods and erosion and increasingly erratic rainfall patterns. In the rainforest ecosystem, the most serious impacts are floods and erosion, heavy and long periods of rainfall, high temperature, uncertainties in the onset of farming season, increased disease incidence and weed infestation.

In the Montane ecosystem, impacts are characterized by delayed onset of rain, reduced harmattan, less rainfall, higher temperature and erratic seasons. In the Guinea savanna ecosystem, the major climate change impacts are a delay in the onset of rainfall, increase in pests and weed infestation, drought, erratic rainfall and higher temperatures. In the Sudan savanna, the most important impacts of climate change are reduced rainfall, drying up of streams/river, delayed onset of rainfall, uncertainty in the onset of farming season and increased incidence of wind, Figure 3.

There was a consensus among households that climate change was responsible for the changes in forest resource use across all the ecological zones, Figure 4. Other drivers of changes in forest resource use result from increased population, development, over-exploitation, shifting cultivation and increased use of

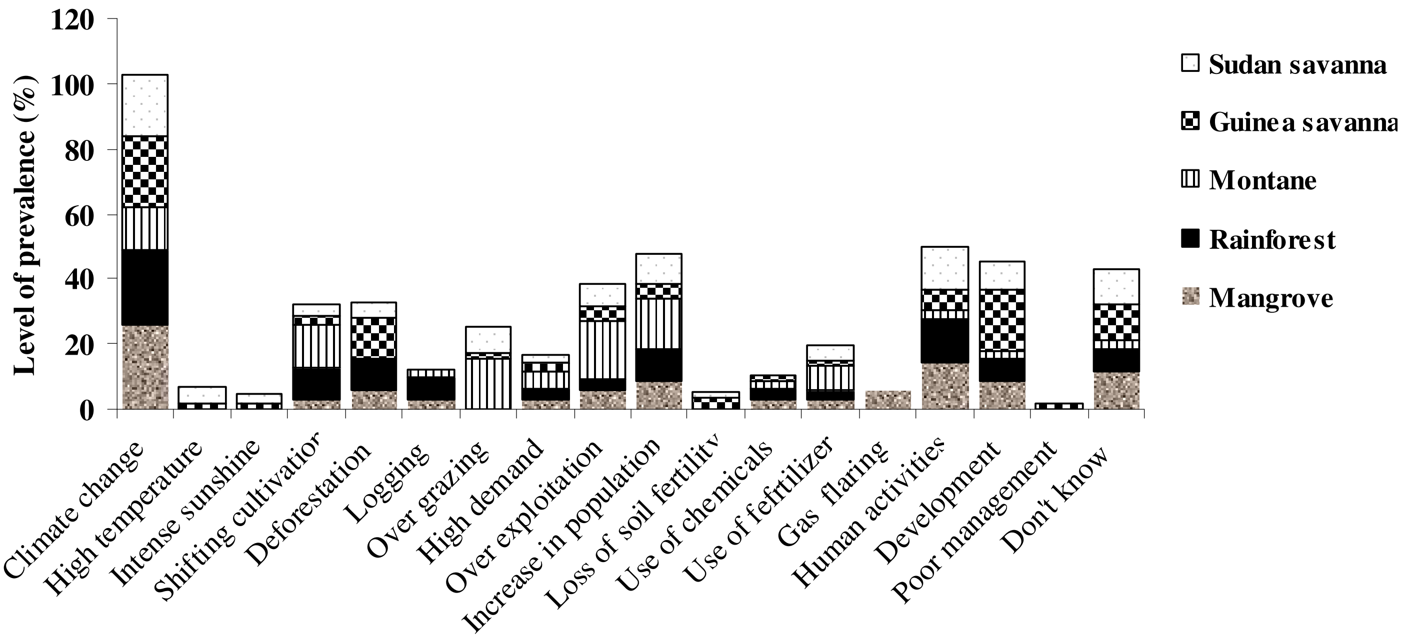

Figure 4. Causes of changes in forest resource use.

fertilizer. Gas flaring was identified as a major driver of change in the mangrove region. Overgrazing was a prominent impact in the montane and savanna areas, in the latter area loss of soil fertility was identified as influencing changes in forest resource availability and use. Logging was a predominant concern in the mangrove, rainforest and montane forest areas.

Adaptation options used by the households to mitigate climate change impacts

Households were asked about any adaptation options over and above their usual agronomic practices, being used specifically to mitigate climate change impacts. The most common response across all the ecological zones is agroforestry, being practiced by 20, 33, 36 and 27% of households in the mangrove, rainforest, montane and Guinea savanna zones respectively, Figure 5. Other options include increased weeding, mulching, plant replacement, and building of shades for plants (especially for young trees). Irrigation is the predominant response in the Sudan savanna. Water shade management is prevalent in the mangrove, rainforest and montane forests. Changing the timing of farming activities, such as increasing the fallow period and avoiding burning, is widely practiced except in the mangrove ecosystem. The use of energy saving cooking stoves and use of local drip irrigation are increasingly used in both the rainforest and the montane forest areas. Increased spraying and selective tree cutting are used in the Rainforest, Montane and the Guinea savanna, while an increasing use of wetland areas is predominant in the Mangrove ecosystem.

DISCUSSION

The discussion will be focused around three key issues: the dependence of communities on forest resources to support livelihoods, how climate change impacts on this and what forest resource management strategies are being implemented to adapt to climate change. How insight from these two areas can be used to develop more effective forest management strategies for Nigerian communities, and the wider West African region, is discussed.

Level of forest dependence in West Africa

Indeed, the results clearly show a high level of dependence on forest resources by rural households, particularly in the mangrove and rainforest ecosystems, gradually declining towards the Sudan savanna. These results corroborate the study by Inonio (2009) that found income from forest resources account for 67% of the total income of the lower income group and some 41% of the highest income group in rural households in Delta State, Nigeria. The average annual value of harvested wild plant products from the Nigerian forests per household was 1,614,133 Naira (US$11,956); the annual net income generated from the harvest of wild plant products per

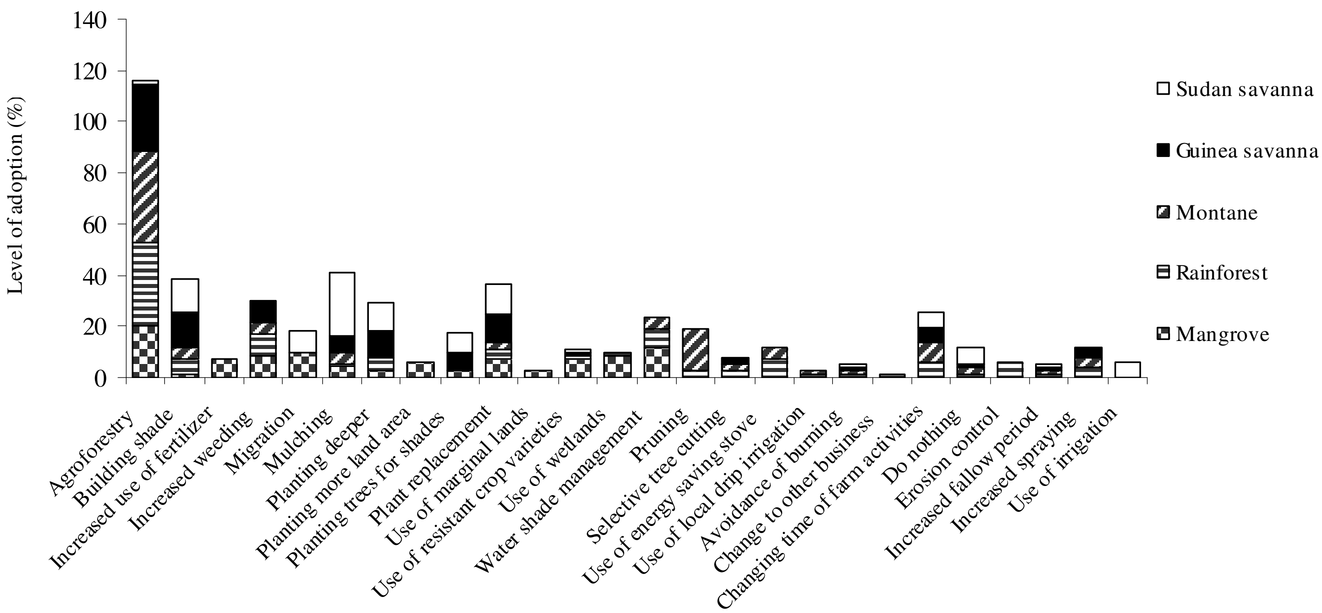

Figure 5. Adaptive forest resource management practices in response to climate change.

household was 910,252 Naira (US$6,742) (Osemeobo, 2005).

Furthermore, the findings also resonate with those of other scholars who identified non-timber forest products (NTFPs) to account for an enormous share of household income (Liedholm and Mead, 1993). Also in southeastern Nigeria alone, 36% of the rural population collected NTFPs daily, accounting for 94% of total income in 1996 (Nweze and Igbokwe, 2000). Wild plant products support a number of occupations in Nigeria; the most profitable being vegetable oil, chewing stick, soap, wine, fuel wood and charcoal production (Osemeobo, 2005). Apart from the provision of food and income, NTFPs are also used for traditional medicines, divination, religious ceremonies and the production of musical instruments (Osemeobo, 1993). There has been a recent and noticeable shift in many African countries and indeed worldwide, from orthodox 'western' medicine to greater use of traditional (herbal) medicines (Akunyili, 2003). Over 90% of Nigerians in rural areas, and 40% in urban areas, depend partly or wholly on traditional medicine (Osemeobo and Ujor, 1999; Bisong and Ajake, 2001). It is therefore not understandable that in spite of their real and potential value, most NTFPs remain grouped as minor forest products; these products rarely feature in statistics of forest use (Aiyeloja and Ajewole, 2006).

Aside from the direct contribution to food and economic wellbeing, there are so much intangible benefits that are closely tied to the social livelihood of the rural people. Rural communities, and to a great extent forest dwellers, have a cultural and religious bond to the forest. Knudston and Suzuki (1992) have explored the protective function of culture within a comparative perspective. Indigenous belief systems have a major protective role in a culture's relationship with the natural world, and in nature's relationship with a culture. Traditional community activities include ceremonies and festivals which utilize NTFP like skins of antelopes, crocodiles, monitor lizards and photon for drums and other musical instruments, kola (*Cola accuminata, C. nitida* and *Garcinia cola)* for sacrifice and prayers, palm wine for traditional ceremonies, festivals and entertainment.

Although our questions focused on the specifics of forest use, the broader ecosystem services and functions provided by forests cover a wide range of ecological, economic, social and cultural considerations and processes (Lindberg et al., 1997). Forests also provide scenic and landscape services and values, this more general set of services highlights ideas of aesthetics as components of forests. Trees play a fundamental role in biogeochemical cycles, improve soil fertility, control erosions, provide shelter belts, fix dune, rehabilitate eroded terrain and provided a 'land bank' that can underpin sustainable livelihoods (Oriola, 2009; Pataki et al., 2011).

Climate change impact on livelihoods

Against the backdrop of forest product dependence, people are highly vulnerable to the impacts of climate change. This is because it acts on the very essence of their sources of livelihoods, upon which they depend on daily basis for their sustenance. In this regard, there was a consensus across all regions that changes in forest resource availability and use was in part, resulting from climate change, Figure 4. Directly, the impact is influencing the biophysical environment, especially water availability and temperature regimes that are interacting to reduce agricultural production and forest resource availability. The impact can be quite extreme and as it was the case in the adaptation practices in the mangrove and Sudan savanna areas ultimately lead to the migration of people from areas of impact, such as associated with desertification and sea level rise, to areas of more marginal forest cover, leading to excessive exploitation and potential conflict. Such an impact is exacerbated by the interaction of other social factors such as development, population growth, agriculture deforestation and urbanization, which can act in concert with climate change to impact on forest resources. Although the nature and intensity of climate change impact vary from place to place, there is no doubt that its effect on peoples' lives and welfare is enormous, and will only increase under current predictions of climate change, especially in Sub-Saharan Africa (Tedesse, 2010).

The impacts of climate change, shown in Table 1, Figure 3 and Appendix 2, vary spatially; in montane areas the impact is relatively low compared to other areas. This result may be attributable to the resilience of the montane ecosystem as a cooler habitat; this has also been identified by NASPA-CCN (2011) in Jos, Plateau State, Nigeria. The relative resilience of the tropical montane forests to climate change and drought has also been documented by Nadkarni and Solano (2002) and Ching et al. (2011). The general impact trend is one of higher rainfall in the south to less rainfall and greater aridity towards the northern region of Nigeria, Figure 4. This result is in line with physical assessments that project an increase in rainfall during the rainy season in the south of Nigeria and a decrease in rainfall amount towards the Sahel savanna though the 21st century (AIACC, 2006; IPCC, 2007; Tompkins and Feudale, 2010).

However, there remains high uncertainty about regional predictions in rainfall in West Africa (Willey, 2008; Buontempo, 2010). Existing rainfall forecast and general circulation models have some fundamental weaknesses when applied to West Africa and have difficulty simulating the annual cycle of rainfall (Redelsperger et al., 2006). A comparison of the Sahelian climate observed (1961-1990) with climates simulated by six general circulation models show a marked rainy season almost throughout the year along with a considerable bias (140-215 mmyear^{-1}) in annual aggregate rainfall estimates as compared to the observed data (ECOWAS-SWAC/OECD, 2008). In some of the models, the start of the rainy season appears one to two months prior to the observed trends (Kamga and Buscarlet, 2006). Such discrepancy in different models on the impact of changing climate regimes further highlights the importance of capturing information on climate and ecosystem variability from other sources such as historical and earth observation data (Pfeifer et al., 2012) or capturing societal perspectives and community memory as presented here. Although it may not be perfect, peoples memory and perception are vital in understanding climatic anomalies, especially where their perceptions are in agreement with measured trends consistent across space, which was the case in this study. More importantly, the information comes from rural based stakeholders who are closely connected to these resources and climate trends which impact on their livelihood on daily basis. Their views can therefore act as an arbiter where such disagreements exist between observed and simulated trends, since they are the ones with actual experiences.

Adaptive forest resource management strategies in the face of climate change

Among the adaptation options identified in this study, agroforestry stood out as the adaptation option of choice for most of the farmers. In addition to providing shade, trees produce fruits and generate additional income. Agwu et al. (2011) also found out that 23% of the rural dwellers in Nigeria use agroforestry as an adaptation option to climate change. Kowero (2011) assert that local communities are using autonomous traditional knowledge and practices in their attempts to cope with current climate viability and change, as they have done throughout time. According to Larwanou et al. (2011), a number of studies have shown that African communities, particularly at the local level, have intimate understanding of surrounding forests and have historically developed coping strategies to adverse climatic conditions, such as using agroforestry systems, and are currently making efforts to adjust to environmental changes being experienced.

In addition, Roberts (2009) suggests that the revival, further development and application of such indigenous knowledge and associated social institutions and governance structures represent an important element in the adaptation responses of forest-dependent people to climate change. Capturing and maximizing the potential of the traditional approaches and knowledge, combined with insights from forest science, will be critical for the development of effective strategies for coping with anticipated changes in forest productivity, in essence, achieving a situation where the use and management of forests are both adapted to anticipated climatic conditions and valued by local communities (Sampson et al., 2000; Parrotta, 2002; Kowero, 2011). The use of agroforestry as an adaptation option to climate change will no doubt continue to expand in all the zones, not just for the fact that it meets the livelihood needs of the farmers, but it is also a source of security to the farmers in times of crop failure, as it serves as an alternative source of income, firewood, stakes and possibly fruits. Enete et al. (2011) identified agroforestry as ranking second (after multiple/intercropping) in profitability of adaptation options and promotes shading and shelter, reduces further depletion of forests, increase food production and at the same time responds to process of rebuilding soil fertility (Okali, 2011). Beyond the local gains of using agroforestry, this practice is recognized by many as a trailblazer in the quest for climate change mitigation for its 'win-win' advantage, combining local use (timber, fruit, shade, medicine, etc) with global issues of carbon sequestration (FAO, 2005; Kleine et al., 2010; Kowero, 2011; Opere et al., 2011; Larwanou, 2011; Larwanou, et al., 2011; Spence, 2005, Ranasinghe, 2004; UNFCCC 2008; Agobia, 1999). Agroforestry has a particular role to play in mitigation of atmospheric accumulation of greenhouse gases, due to potential for carbon sequestration, improve soil nutrient, nutrient uptake, water percolation, aeration, water recharge and general soil water balance, thus should be encouraged (Louise et al., 2007; Prabhakar and Shaw, 2007; IPCC, 2000).

A special form of agroforestry identified in this study is watershed management, used to moderate water flow and protect streams from drying up. Farmers avoid cutting the forest and leave strips of about ten meters between their farms and the streams. A number of communities also practice similar watershed management practices in other countries (Kerr et al., 2002; Farrington and Lobo, 1997; Turton and Bottrall, 1997; White and Runge, 1995; Ravnborg and Guerrero, 1999). Findings also show that drought-induced impacts in India have reduced the average crop income (as a percentage of total household income) in non-watershed managed farms from 44 to 12%, this share remained unchanged at about 36% in the adjoining watershed managed farms (Shiferaw et al., 2005). Another form of watershed management is selective tree cutting which provides alternative shade for arable crops in Nigeria. In addition Nyong et al. (2007) reports that local farmers' increase the fallow period of cultivation, which encourages the development of forests and diminish moisture and nutrient deficiencies (Mertz, 2009; Skinner, 2002; Swearingen and Bencherifa, 2000) as a measure to address climate change-related impacts.

Mulching was also identified to be on the increase in all the zones. Mulching protects sown seeds by moderating soil temperatures, suppressing diseases and harmful pests, and conserving soil moisture (Nyong et al., 2007; Salinger, 2005; Ishaya and Abaje, 2008). Agwu et al. (2011) also found out that 74% of Nigerian farmers use mulching as an adaptation to climate change. Schafer (1989) and Osunade (1994) also report the use of mulching in the Sahel to conserve carbon in soils and this is becoming increasingly common with the rise of organic farming and potential for reducing Greenhouse Gas Emissions (Nyong et al., 2007).

Furthermore, increased time spent on weeding across the ecological zones, due to increased rainfall during the rainy season is common, particularly in the rainforest. Farms are weeded two or more times than usual; this resonates with the findings of Apata et al. (2009), Agwu et al. (2011); Enete et al. (2011) and Ozor et al. (2012) who found out that 64% of Nigerian farmers experience increased weeding as an impact of climate change. Due to uncertainties in farming season, particularly increasingly erratic rainfall patterns, households change their time of farming activities to start planting whenever they are sure that the rains have stabilized. Agwu et al. (2011) found out that 38% of farmers in West Africa change their planting dates in response to changes in rainfall pattern due to climate change. Swearingen and Bencherifa (2000), Smit and Skinner (2002), Salinger (2005), Howden et al. (2007), Ishaya and Abaje (2008), Deressa et al. (2009), Apata et al. (2009) and Enete et al. (2011) also identified the change in the timing of farm operations in different parts of Africa.

Associated with changing of planting dates, is the use of irrigation in order to cope with water shortages and, or plant in normal seasons when there is no rainfall. Irrigation practices improve farm productivity and enable diversification of production in light of climate-related changes (Brklacich et al., 1997; Klassen and Gilpen, 1998). Implementing irrigation practices involves the introduction or the enhancement of specific water management innovations including centre pivot irrigation, dormant season irrigation, drip irrigation, gravity irrigation, pipe irrigation and sprinkler irrigation (Smit, 1993). In the rainforest and montane regions, locally fabricated drip irrigation is practiced to supply water to newly transplanted seedlings to help establishment. It is a unique form of irrigation predominantly used among cocoa farmers in Cross River State Nigeria. After repeated years of crop failure due to drought, some farmers trialed a drip irrigation system using empty cans with small perforation at the base, wide enough for water to drip (approximately one drop in every 5 -10 s) with the other end open, (in some cases, fine sand is poured into the base to regulate water flow), the cans are filled with water and with a stick each is tied just above the base of each plant, until the cocoa plants are well established. In this way most farmers have recorded up to 100% success in plant establishment, though it is predominant among farms close to the streams as this might not be cost effective elsewhere. Findings have also shown that a wide variety of local technologies have been developed in semi-arid and arid regions, to harvest and conserve water in traditional silvo-pastoral and agroforestry systems (Smit and Skinner, 2002; Laureano, 2005; Osman-Elasha et al., 2006; Larwanou, 2011).

The increased use of wetland is prevalent in the mangrove ecosystem where farmers take advantage of areas periodically flooded by fresh water from streams to cultivate vegetables and flood tolerant crops. The resilience and increased use of such groundwater wetlands in the face of climate change has also been reported by Morton (2007); Deressa et al. (2009), Fernández (2010), Daniel and Kauffman (2011) and Murdiyarso et al. (2012). In general, irrigation increases

Figure 6. Energy saving cook stove before the kitchen wall is covered.

soil moisture in the light of moisture deficiencies associated with climate change and reduce the risk of income loss due to decreasing precipitation, increasing evaporation and recurring drought (Smit and Skinner, 2002).

Apart from the different on-farm adaptation techniques, households also practice some adaptation options which also saves them time and cost. One of such options is the use of improved wood-burning cooking stoves (ICS) which was developed in the mid-1970s. This option addresses the two main drawbacks of open fires, by including a combustion chamber and a tube to take the smoke outdoors (Troncoso et al., 2007). The use of ICS, especially in the rainforest and montane areas by rural households is regarded as another ‘win-win’ option; as it is not just effective in climate change abatement (saving the forest by reducing the amount of fuel wood used for cooking), but very cost effective. The ICS is made from locally available materials, Figure 6. During cooking, up to one quarter of the usual amount of firewood used in open fire stoves are used, while retaining virtually all the heat directly below the pot and the smoke is channeled outside the wall through the hollow in the bamboo stick. Nangoma and Nangoma (2007) reports that the ICS uses less firewood than an open fireplace, produces more heat energy, produces less smoke and runs on any form of available fuel. In places where this stove has been introduced in Nigeria, virtually all the households in the communities have adopted the ICS as the women have more time for profitable ventures like farming, trading, social activities which help improve their socioeconomic wellbeing. Also, impacts on forest are reduced with potential higher carbon sequestration.

Since the burden of preparing household meal lies on the women in most traditional homes in developing countries, the ICS saves them from being exposed to the physical challenges occasioned by the use of excessive wood in traditional wood burning open stove. In addition the smoke causes a lot of health impact, especially for the women and their children who they carry on their backs while cooking. The association of adoption of climate change adaptation options, especially ICS with greater opportunity for social progress has also been reported by the World Health Organization (2006) in improving health, World Bank (2009) and Bennett (2013) with regard to other social benefits. A report by the WHO estimates that 4 million people, in particular women and children, die prematurely from smoke inhalation, respiratory illnesses or incur long-term physical harm from collecting fuel.

Particularly, in Africa, Bennett (2006) has noted that the use of ICS addresses most of the Millennium Development Goals (MDGs) as follows: by reducing the required fuel consumption by two-thirds, poverty is reduced and more money is available for other purposes (MDG 1). Less time is needed for collecting fuel by women and children which allows more time for other activities such as education (MDG 2 and 3); it is physically less demanding and reduces the exposure of women to the risk of physical attack. The health and safety of mothers and children will also improve because of substantial lower smoke levels (MDG 4 and 5).

Moreover, the ICS ensures environmental sustainability, because of lower fuel consumption and reduced deforestation (MDG 7) (Bennett, 2006). These and other concerns clearly justify the need for urgent integration of ICS into the socioeconomic lives of rural households in the developing world.

Bailis et al. (2009) reports that dozens of organizations have developed projects to promote the use of ICS since the mid-1990s; one of such was the Mexican Patsari Stove Project that was well suited to local cooking practices, burnt less wood by over 60% relative to traditional cooking stoves. Interventions for disseminating ICS since the 1970s were mainly designed for increasing fuel efficiency, often because of a link between deforestation and household energy use (Eckholm, 1975; Arnold et al*.,* 2003; Ruiz-Mercado, 2011). Thus, there are more than 160 cook stove programs running in the world, ranging in size, scope, type of stove disseminated, approach to technological design, dissemination and financial mechanisms. The two largest and longest programs are credited with introducing approximately 210 million stoves between them, 85 % in China and 15% in India, and affecting the lives of more than a billion people (Gifford, 2010; Smith, 2007).

In the case of India, reducing deforestation was often the main motivation (Bailis, 2007). The Chinese program focused primarily on increasing fuel efficiency to sustain local welfare and stem the demand for fossil fuels in rural areas (Smith et al., 1993). In the light of the foregoing, regardless of how beneficial these energy use option could be in the short run, what their long time implication can be is yet unclear. This is because of the fear among certain scholars that the shift may be unsustainable in the long run. Nevertheless, they offer good opportunities for poverty reduction, environmental protection and general socioeconomic wellbeing of the rural dwellers if they are effectively integrated into their everyday lives.

Implication of climate change adaptation for Africa

In addition to the plethora of benefits from adaptation as has been x-rayed in this paper, it is also heart-warming that a series of global modeling analyses show that the benefits from undertaking adaptation may outweigh the costs by a factor of about two in Africa (African Development Bank (AfDB) and African Development Fund (AfDF), 2011), thus giving hope for the future of climate change adaptation in the region. In addition, it is evident that Africa possesses a wealth of social networks that have enabled people to survive throughout an environment of harsh climatic conditions. These networks represent safety nets for many of its inhabitants through compensation for their low financial incomes and helping many maintain their livelihoods. These networks should be built upon and further strengthened (Osman-Elasha, 2013).

Nevertheless, despite these successes stories, limited scientific capacity and other scientific resources which combine as factors to frustrate adaptation has been identified (Washington et al*.,* 2004, 2006). In addition, evidence abounds in Africa of an erosion of coping and adaptive strategies as a result of varying land-use, biophysical changes, socio-political and cultural stresses. Thus, these traditional coping strategies may not be sufficient, either currently or in the future, and may lead to unsustainable responses in the longer run. Erosion of traditional coping responses not only reduces resilience to the next climatic shock but also to the full range of shocks and stresses to which the poor are exposed (DFID, 2004). These short-term responses and isolated projects (Sachs, 2005), good as they may be are not enough, rather, long term solutions that could be considered include mainstreaming adaptation into national development processes (Huq and Reid, 2004; Dougherty and Osman, 2005). Bok et al. (2007) identified a complex range of factors, including behavioural economics (Grothmann and Patt, 2005), national aspirations and socio-political goals (Haddad, 2005), governance, civil and political rights, literacy, economic well-being and stability, demographic structure, global interconnectivity, institutional stability and well-being, and natural resource dependence (Adger and Vincent, 2005), as emerging and powerful determinants of vulnerability and the capacity to adapt to climate change.

In order to address some of these challenges, build resilience and strengthen adaptation capacity in Africa, several scholars have posited different options at the disposal of stakeholders, such as:

(1) Approaches that address multiple environmental stresses and factors hold the greatest promise for Africa, particularly given the limitations in capacity, in terms of both human capacity and financial resources. Efforts to design implementation strategies that address land degradation, loss of biological diversity and ecosystem services, as well as adaptation to climate change, such as through enhancing adaptive capacity, will be more likely to succeed than uncoordinated efforts (Osman-Elasha, 2013).

(2) Micro-financing and other social safety nets and social welfare grants, as a means to enhance adaptation to current and future shocks and stresses, may be successful in overcoming such constraints if supported by local institutional arrangements on a long-term sustainable basis (Ellis and Bahiigwa, 2003; Chigwada, 2005).

(3) Incorporating indigenous knowledge into climate change policies can lead to the development of effective adaptation strategies that are cost-effective, participatory and sustainable (Robinson and Herbert, 2001).

(4) A series of more targeted adaptation investments are required and it is crucial that African decision-makers factor climate change into all long term strategic decisions starting immediately (AfDB and AfDF, 2011).
(5) Adaptation needs to be complemented with global emission reductions. Although the policy focus in Africa is rightly on adaptation, the global need to reduce greenhouse gas emissions remains unchanged (AfDB and AfDF, 2011).
Thus, the successful implementation of some or all of these in addition to other development strategies that focus on enhancing the livelihoods of the rural people will go a long way towards enhancing the their ability to cope with climate change.

Conclusion

Rural households in Nigeria are dependent on forests for supplementing of their livelihoods; income from the forest ranges from about 14% in the Sudan savanna to 47% in the mangrove ecosystem. In addition to providing direct income to the rural dwellers, forest resources generate employment; provide medicines and other products for the urban population, international trade, social welfare and environmental benefits. Climate change impacts, particularly increase flooding and erosion; erratic rainfall; high temperature; uncertainties in the onset of farming season; high disease and pest infestation; loss of soil fertility; strong wind and excessive rainfall in the south to severe water shortage in the north of Nigeria. Over 75% of the household agree that there have been adverse impacts of climate change, except in montane forests where the majority of the households (67%) assert that there has not been a significant change in forest resources. Among the adaptation options used by the households, agroforestry is predominant; increased weeding, selective tree cutting, avoidance of burning, use of energy saving stoves, watershed management, pruning, the use of local drip irrigation, changing planting dates, mulching, use of drought resistant varieties, increased spraying and plant replacement are also used.
There is no doubt that forest resources are an indispensable asset to the survival and livelihood of the rural West African households. Thus, adverse effect on forest resources will have serious consequences on the livelihoods and health of many households across Nigeria and the wider West African region. The adverse effects of climate change are already noticeable, with adaptation choices being made at the household level with concomitant viewable social and economic progress. There is an urgent need for a concerted effort among stakeholders, to invest in adaptation options that are not just effective, but sustainable. In addition, the information on the social perspectives of climate change as presented here are very useful in the hands of policy makers and development practitioners in formulating policies and strategies that are compatible with local norms and values. This will ensure a continuous flow of forest resources for the forest dependent poor.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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Impact of desilting of irrigation tanks on productivity of crop yield and profitability of farm income

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Irrigation tanks are one of the major water and common property resources in Southern Peninsular India. Declination of irrigation tanks threatens the agriculture productivity and water availability in the South and Southeast Asia especially in southern Peninsular India and Sri Lanka. The storage capacity of the tank has been decreased due to the factors such as siltation of supply channels, tank bed and irrigation courses. In order to reduce the factors causing decrease in storage capacity, desilting of tank has been chosen as rehabilitation work. Desilting of tank beds and supply channels may yield the expected benefit of crop productivity and farmer income. The study has evaluated the benefits and financial structure of the desilting of irrigation tanks project in the villages Ponpadi, district Thiruvallur in Tamil Nadu where a project under Public Welfare Department in Tamilnadu. Productivity indicator of yield has increased due to restoration and is from 4800 to 5400 in first season and 4425 to 5400 in second season. Profitability indicator of benefit cost ratio is increased from 0.64 to 1.04 in first season and from 1.13 to 1.31 in second season. The restoration project aims to bring about increase in agricultural production through improving groundwater recharge and consequently to improve the economic, social and environmental wellbeing of the rural population.

Key words: Tank irrigation, agriculture, crop productivity, desiltation, irrigation tanks.

INTRODUCTION

One of the most ingenious technologies appropriate to the peninsular India has been the creation of tank irrigation systems. Ingenious because, the tanks capture the runoff resulting from the unpredictable monsoon rains having a wide diversity of distribution (Shanmugam, 2001). Irrigation tanks have been serving both as flood moderators in times of heavy rainfall and as drought mitigators in times of long dry spell (Vasimalai, 2006).

The improved productivity of wells due to groundwater recharge is by far the most valuable benefit to farmers associated with tanks (Shah and Raju, 2002). Tank irrigation contributes significantly to agricultural production in the parts of South and Southeast Asia. Especially in South India and Sri Lanka, tank irrigation has a long history and many currently used tanks were constructed in the past centuries. Irrigation tanks account

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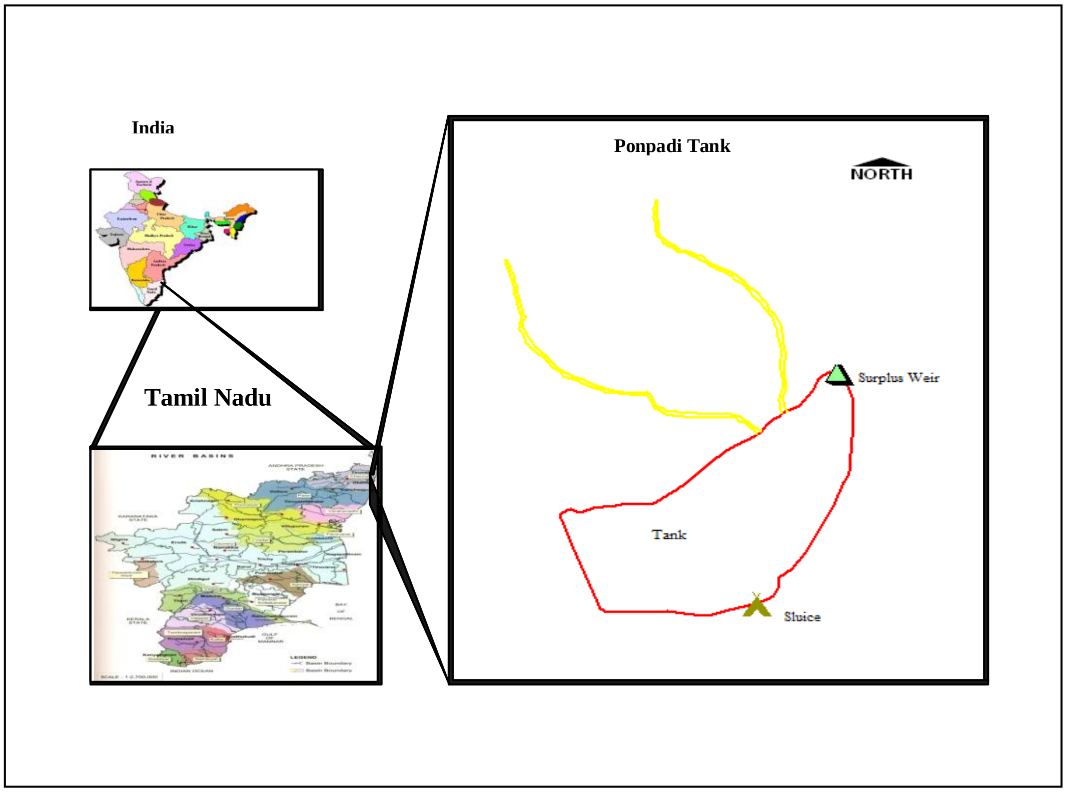

Figure 1. Map of a study village.

for over 30% of the total irrigated area in South India and over 40% of the irrigated rice in Sri Lanka (Palanisami and Flinn, 1988). In India, the largest concentration of tanks are found in the three southern states of Andhra Pradesh, Karnataka and Tamil Nadu and the union territory of Pondicherry, which account for nearly 60% of India's tank-irrigated area (Vaidyanathan, 2001). Over the centuries, locally built water storage systems (e.g, tanks in South India, Johads in Rajasthan), have acted as insulation against droughts, helped in recharging groundwater, provided crucial irrigation for crop production, functioned as a source of multiple uses for the village community and played a role in the maintenance of a good natural environment (Raju and Shah, 2000). Tanks involve a combination of land and water resources that can be used for brick making, trees and grazing. In water-scarce regions, it is therefore not surprising that tanks are used for a variety of productive and domestic uses (Palanisami and Meinzen-Dick, 2001).

Encroachments, privatization and government appropriation of the tanks have been the main outcomes of failures of the local authority to enforce the institutional arrangement under the common property resource management (Vaidyanathan and Sivasubramaniyan, 2004). Due to rainfall uncertainties and lack of community involvement in tank management and maintenance inadequate and unreliable water supply to the tank, the performance has declined over the years (Sakthivadivel, 2005). In addition, there are problems such as poorly maintained structures (bund, surplus weirs) above the outlet. Catchment is mismanaged and forest land adjacent to the catchment has already been converted to human settlement by the Government. There are severe encroachments in the tank foreshore. Siltation of tank beds has reduced their water storage capacities (Palanisami, 2006). The accumulation of silt in the tank basin/bed has reduced the water-holding capacity of the tanks; the construction of dams/reservoirs in the upper watershed or catchment area has prevented the water supplies from reaching downstream tanks (Sivasubramanian, 2006); tank renovation and rejuvenation with peoples' contribution and looked upon as cost effective, equitable and powerful tool to alleviate rural poverty. Restoring the physical conditions of tanks through rehabilitation and modernizations is of course the necessary condition for doing this (Sakthivadivel and Gomathinayagam, 2004).

The present study attempts to examine the impact of partial desilting of irrigation tanks through a comparative analysis between, "before restoration" and "after restoration" of the selected study tanks.

MATERIALS AND METHODS

Ponpadi tank is situated in Thiruthani block of Thiruvallur district in Tamil Nadu, India as shown in Figure 1. The latitude and longitude

Table 1. Hydrology and hydraulic particulars of the tank.

S/N	Tank components	Quantity
1	Tank bund level	97.10 m
2	Full tank level	95.20 m
3	Maximum water level	95.60 m
4	Command area	145.35 ha
5	Crop	Paddy, sugarcane
6	Number of sluices	1

of the tank are 13°13’ 58’’ N and 79°35’ 59’’ E, respectively with an altitude of 99 m above m.s.l. It is situated about 0.6 km from Ponpadi village. Ponpadi tank is rainfed and a non-system tank has only one sluice, receives drainage from its free catchment of 10.35 km^2. The catchment is classified as good one. Irrigation depends on the tank as well as bore and open wells. The command area for the Ponpadi tank is about 145.35 ha. The works included desilting of the tanks and tank bund strengthening was carried out under the Public Works Department (PWD). The total expenditure incurred on restoration was Rs 4.00 lakhs which was incurred by the PWD. Secondary data of hydrology and hydraulic particulars of the tank is given in Table 1.

The total populations of landholders in the study village have been selected for assessing the crop productivity. 128 sample respondents were selected of which 83 respondents (65%) are total population of landholders. Their command area is 145.35 ha. The remaining 45 respondents (35%) are the households of landless labour. However, the households of landless people have been selected randomly. In Ponpadi village, paddy and vegetables are major crops and also some farmers cultivate sugarcane.

Quantitative approaches have been used for the evaluation. Data were collected through group discussion with different categories of farmers. However, the study mainly relies on the data collected by using an interview schedule. Three structured questionnaires were prepared in order to elicit information from the implementing schemes, villages and household levels. The data obtained through quantitative methods were classified and analyzed using a Statistical Package for Social Sciences (SPSS)

Profitability analysis involved assessment of the costs and benefits of the farm income, benefit of irrigated area, crop production and crop yield related to before and after implementation of the restoration schemes.

Evaluation of impact measures for desilting irrigation tanks

Water availability indices

Groundwater levels as observed from open wells can be used for determining changes by comparing water table and water yield through duration of pumping hours with that of before implementation of restoration schemes. Some indirect measures include increase in irrigated area by sources of tank and wells.

Productivity

The crop productivity and cropping pattern are in terms of production and yield per hectare. Cropping intensity is taken as the ratio of gross cropped area to the net sown area (Palanisami and Kumar, 2004)

Cropping intensity = (Gross cropped area / Net sown area) ×100 (1)

Net revenue

Input and output data were collected from the village at two points of time, that is, before the implementation of development program and after the development program by using the stratified sampling method. To estimate the financial costs and revenues of irrigated crop activities, information was collected on the type of crops, crop yields, quantity of inputs (seed, fertilizer, fuel, labor, insecticides and fungicides) and input and output prices.

Crop yields, output prices and labour data were collected at farm household levels, while input use and input prices were collected at scheme level. The local wage rate was used as the opportunity cost for labour. The results and data used for cost and revenue analysis were standardized for an hectare. The net revenue (Mengistu, 2008) obtained by farmers was calculated as:

$$GM = Q_y P_y - \sum X_i P_{xi} \quad (2)$$

Where: GM, Gross margin; Q_y, total quantity of crops in bags; P_y, total price of the crop yield; X_i, quantity of the input used (bags); P_{xi}, price per unit of the input (Rs).

Profitability

Profitability analysis involved assessment of the costs and benefits of the farm income for before and after implementation of the restoration schemes.

RESULTS AND DISCUSSION

Impact of desilting on irrigated area

In the village, the changes in irrigated areas of paddy and vegetables by tank and well irrigation due to restorations of the tanks were analyzed and the results are presented in Table 2.

Paddy cropped area in Ponpadi has increased from 64.75 to 83.77 ha with tank and well waters due to restoration. Tank water alone increased the area from 15.38 to 25.29 ha. The corresponding values for the vegetables area from 12.95 to 13.76 ha with tank and well and from 1.21 to 1.62 ha with tank alone. The non-irrigated area has come down to 20.56 from 50.71 ha. The area under vegetables cultivations have increased significantly, which clearly indicates that water was available for irrigating the crops either through the tanks

Table 2. Change in irrigated area before and after desilting.

S/N	Details		Cropped area (ha)	
			BR	AR
1	Total cultivated land by tank and well irrigation	Paddy	64.75	83.77
		Vegetable	12.95	13.76
		Total	77.70	97.53
2	Total cultivated land by tank irrigation	Paddy	15.38	25.29
		Vegetable	1.21	1.62
		Total	16.59	26.91
3	Total cultivated land		94.29	124.44
4	Total existing irrigated land		145	145
5	Non irrigated land		50.71	20.56

BR- Before restoration; AR- After restoration.

Table 3. Changes in cropping intensity.

S/N	Details	Cropping intensity (%)		Percentage change in cropping intensity (+/-)
		BR	AR	
1	Total cultivated land by tank and well irrigation	54	67	13
2	Total cultivated land by tank irrigation	11	19	8
3	Non irrigated land	35	14	-21

BR- Before restoration; AR- After restoration.

or the wells. Whatever may be the case, it should have been possible only by the consequences of tank restoration schemes. The effect of restoration measures is reflected by leading to better use of land, which is measured in terms of cropping intensity may be through increased groundwater recharge. Hence, the farmers grow crops throughout the year based on availability of water. Cropping intensity by using tank and well water for irrigation before and after implementation of the restoration schemes are presented in Table 3.

Paddy and vegetables are major crops and also some farmers cultivate sugarcane. Cropping intensity by tank and well irrigation increased due to restoration schemes from 54 to 67%. Cropping intensity of paddy by using tank irrigation is increased from 11 to 19%, respectively. The cropping intensity of non-irrigated land was reduced from 35 to 14% in these villages, respectively. Desilting of tank increased the cropping intensity. They have also improved the groundwater levels in the command area thereby increased the cropped area and cropping intensity.

Desilting of tank on increased irrigated area

Changes in area under irrigation are prime indicators of any impact of desilting of irrigation tanks on rural livelihoods, especially where the major livelihood activity is farming. It is observed that proportion of area under irrigation has been increased, though marginally, among all the households in study villages after the restoration of tanks as shown in Table 4. The irrigated area has increased in Season I: 22, 21, 62 and 72% and in Season II: 19, 62, 98 and 107% in large, middle, small and marginal farms, respectively. Therefore, the impact of tank restoration is significant increase in irrigated area among the large, middle, small and marginal farms in all three villages as shown in Table 4.

Irrigating intensity is taken as the ratio of gross irrigated area to the net area which has also increased after restoration is clearly indicated in Figure 2. Increased irrigating intensity changes in ranges between 25 and 156%. The restoration of tanks have provided an opportunity to expand area under irrigation and increased water availability during irrigation.

Major crop cultivated in the village is paddy and minimum quantity of vegetable crop is also grown here. Table 5 presents area of vegetable crop under irrigation before and after restoration schemes

All respondents in Ponpadi cultivated vegetable crops like lady's finger, cucumber, pumpkin etc. Implementation of the desilting of irrigation tanks has increased the cropping area of vegetables in both seasons.

Paired T-test analysis was carried out to identify the

Table 4. Changes in Irrigated area.

Type of season	Farm category	Total number of farmers	Total irrigated area (ha)		Changes in irrigated area (%)
			BR	AR	
I	Large	9	31.57	38.45	22
	Middle	16	22.46	27.11	21
	Small	20	14.37	23.27	62
	Marginal	38	11.74	20.23	72
	Total	83	80.14	109.06	36
II	Large	9	12.95	15.38	19
	Middle	16	11.74	19.02	62
	Small	20	9.51	18.82	98
	Marginal	38	5.87	12.75	117
	Total	83	40.07	65.96	65

BR- Before restoration; AR- After restoration.

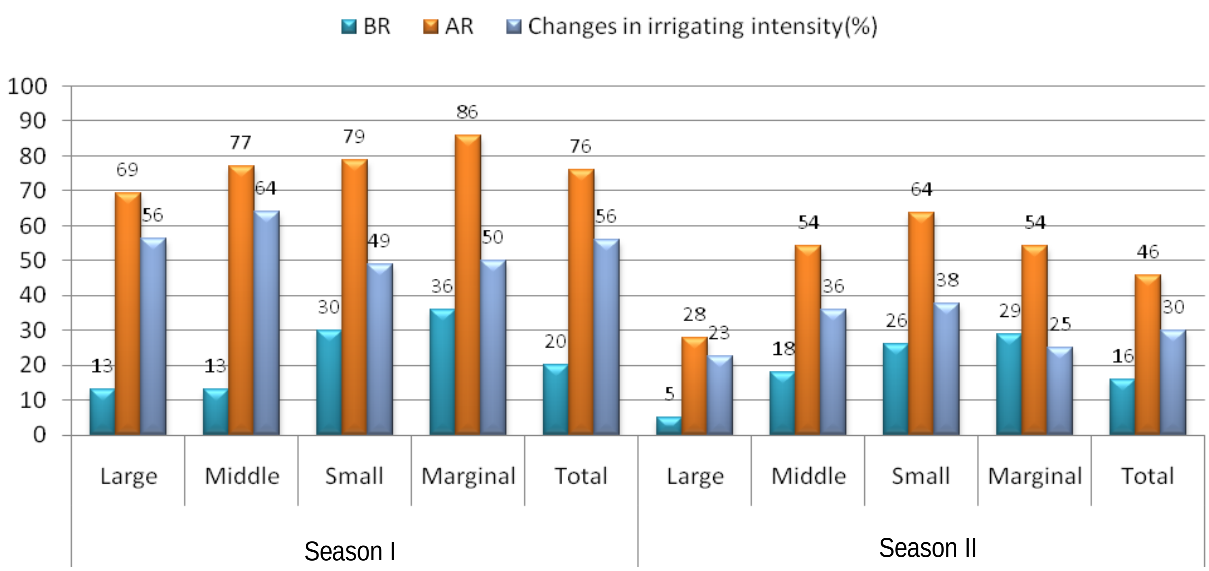

Figure 2. Changes in irrigating intensity.

impact of restoration of tanks and to investigate the significant relationship between before and after impact of restoration. Our null hypothesis is that the programme is not effective, that is, there is no difference between the productivity area before and after the program. The alternative hypothesis is that the programme is effective and the cropped area measured after is higher than that before restoration. Productivity area between before and after restoration of tank in Ponpadi village has a statistically significant mean as shown in Table 6. During Season I, t (78) = -2.095, P = 0.000 which is less than 0.05. In Season II, t (78) = -1.810, P = 0.000 which is less than 0.05. Therefore, the null hypothesis is rejected and the fitness is effective at 5% significant level. Hence, there is a correlation between restoration cultivation crop areas.

Desilting of tank on increased crop yield

Changes in cropped area are reflected in changes in crop productivity, which are measured in tones of food crop per hectare. The following analysis reveals that significant improvement is noticed in the yield of paddy crop in the restored irrigation tanks. The yield is measured in bags (1 Bag = 75 kg). Overall, changes in productivity of crop yield ranges among the farms in the ranges between 4 and 19% in the first season and 2 and

Table 5. Irrigated area of vegetables among different categories of farmers.

Type of season	Type of farm	Total irrigated area (ha)		Changes in irrigated area (%)
		Before	After	
I	Large	10	10	-
	Middle	1.21	2.02	3
	Small	2.83	3.24	1
	Marginal	-	-	-
	Total	14.04	15.26	1
II	Large	-	-	-
	Middle	1.21	2.02	3
	Small	2.83	3.24	1
	Marginal	-	-	1
	Total	4.04	5.26	1

BR- Before restoration; AR- After restoration.

Table 6. Paired t- test for irrigated area.

Irrigate area between BR and AR	Mean	Standard deviation	Standard error mean	95% confidence interval of the difference		T	Df	Sig
Season I	1.774	7.758	0.847	0.090	3.457	2.095	82	0.039
Season II	0.821	4.160	0.454	0.081	1.724	1.810	82	0.074

BR- Before restoration; AR- After restoration.

Table 7. Change in crop yield before and after desilting of tank.

Type of season	Types of farm	Crop yield per farmer (Bags)			
		BR		AR	
		Mean	SD	Mean	SD
I	Large	202	178	274	238
	Middle	81	56	117	81
	Small	55	34	89	53
	Marginal	25	23	46	26
	Total	64	85	94	112
II	Large	38	84	54	120
	Middle	44	63	78	94
	Small	28	38	66	57
	Marginal	14	24	33	30
	Total	26	47	52	68

BR- Before restoration; AR- After restoration.

19% in the second season. Total crop yield increased due to restoration in Season I was 13% and in Season II was 22%. Thus, in future years it is expected that the yield of paddy will continue to increase. Changes in cropped area are reflected in changes in crop productivity, which are measured in tones of food crop per hectare. The following analysis reveals that significant improvement is noticed in the yield of paddy crop in the restored irrigation tanks. The yield is measured in kg or tonnes per hectare. Season wise and farm wise yield of paddy crop before and after restoration are presented in Table 7.

Table 8. Paired t-test for crop yield.

Crop yield between BR and AR	Mean	Standard deviation	Standard error mean	95% confidence interval of the difference		t	Df	Sig
				Lower	Upper			
Season I	53	65	4	46	52	3.41	83	0.048
Season II	43	58	5	37	46	2.56	65	0.049

BR- Before restoration; AR- After restoration.

Table 9. Paired sample test for employment opportunity.

Irrigate area between BR and AR	Mean	Standard deviation	Standard error mean	95% confidence interval of the difference		t	Df	Sig
				Lower	Upper			
I	36	48	5	26	46	7.19	83	0.000
II	15	28	3	10	21	5.38	83	0.000

BR- Before restoration; AR- After restoration.

The results of the crop yield indicate that this productivity of yield is higher in the after restoration than in before restoration. The percentage deviation in the crop yield of paddy crop reflects a significant change in the crop yield of after the restoration over the productivity of crop yield of before restoration. The analysis reveals significant improvement in the crop yield due to restoration of tanks in all three villages among all the farms.

Crop yield between before and after restoration of tank in Ponpadi village has a statistically significant meanas given in Table 8. During Season I, t (78) = -3.41, P = 0.000 which is less than 0.05. In Season II, t (78) = -2.56, P = 0.000 which is less than 0.05. Therefore, the null hypothesis is rejected and the fitness is effective at 5% significant level. The values of 't' in both seasons are highly significant. Hence, there is a correlation between before and after restoration on crop yield.

Impact of tank restoration on employment opportunity for land less labour

The quantitative survey collected data on days was employed through working the farm labour during the cultivation period. The average number of days employed has been analyzed. Paired T- test analysis was carried out to identify the impact of restoration of tanks and to investigate the significant relationship between before and after impact of restoration as presented in Table 9. Our null hypothesis is that the programme is not effective, that is, there is no difference between the employment opportunity for before and after the program. The alternative hypothesis is that the programme is effective and the employment opportunity after is higher than that before restoration.

Employment opportunities between before and after restoration of tank in Ponpadi village have a statistically significant mean. During the Season I, t (78) = -2.095, P = 0.000 which is less than 0.05. In Season II, t (78) = -1.810, P = 0.000 which is less than 0.05. Therefore, the null hypothesis is rejected and the fitness is effective at 5% significant level and t-value is significant in both seasons. Hence, there is a correlation between restoration employment opportunities.

Productivity and profitability due to restoration of tank

Impact of irrigation tank development on crop yield and income is due to the improvement in agriculture. In Table 10, the analysis is based on productivity of yield and profitability of farmer's income before and after restoration of tank. Profitable indicators of total cost, net income and benefit cost ratio and productivity indicator of crop yield after restoration is significantly higher than that of before restoration. However, cost benefit ratio is slightly higher than that of before because input cost of labour wages, fertilizer, machinery etc are very high compared to before.

Conclusion

Desilting of irrigation tank aims to bring about increase in agricultural production through improving groundwater recharge and consequently to improve the economic, social and environmental wellbeing of the rural population. Tank irrigation system plays a role in meeting

Table 10. Productivity of crop yield and profitability of income.

S/N	Indicators for productivity and profitability	Season I		Season II	
		BR	AR	BR	AR
1	Total cost (RS)	2339260	3068175	995370	1379350
2	Net income (Rs)	1499990	3202275	1129055	1810650
3	Total area (ha)	145	145	145	145
4	Total yield	4800	5400	4425	5400
5	Total cost of Rs/ha	16133	21160	6865	9513
6	Net income	10345	22085	7787	12487
7	NI/TC ratio	0.64	1.04	1.13	1.31
8	Cost of Rs/kg	3	4	2	2

BR- Before restoration' AR- after restoration.

the growing demand for food and to achieve long-term food security. The results of desilting of tank carried out in Ponpadi shows that increasing recharge in the command area wells and correspondingly increasing irrigated area proves productivity of crop and profitability of income. The high yields obtained in irrigation and other benefits such as increased incomes, employment creation, food security, are indication that irrigation can bring a sustainable agriculture and economic development without severe effect on the environment.

Conflict of Interests

The authors have not declared any conflict of interests

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Full Length Research Paper

Modeling of rapeseed at maturity stage using 3D unorganized point clouds and digital images

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Creating 3D plant models is often a difficult and laborious task. To make it easier and more natural, the integration of digital images and 3D unorganized point clouds from a digitizer provides a promising approach for rapeseed model generation. In the present study, 3D unorganized point clouds and digital images were incorporated in the generation of complex models of rapeseeds at maturity stage. Unorganized point clouds and image sequences were taken from different viewpoints using a 3D digitizer. The 3D unorganized points and image sequences were used for the automated registration of all data sets from all the viewpoints, which is pair-wise registration. Later, all the pair-wise registration parameters were used as initial transformation parameters for multiple registrations. The next procedure generated a surface model by triangulated irregular network using all the point clouds. The capabilities of our system were demonstrated through real data sets. Experimental results showed that the average normal distances between the two scans were less than 0.3 mm after simultaneous registration, which indicated that the proposed methodology is effective and efficient.

Key words: Rapeseed, 3D modeling, unorganized point clouds.

INTRODUCTION

Rapeseed is a crop grown mainly for its high-quality oil and protein. It provides a versatile kind of oil, which is used for cooking and frying as well as fuel or raw material for the chemical industry. In the face of global climate change, rapeseed can play an important role as a future source of renewable energy. The morphogenesis and architecture of rapeseed at maturity stage are critical factors affecting the estimation of seed yields. However, they are not yet fully studied because of the structure complexity of the rapeseed at maturity stage as well as the lack of appropriate tools for three-dimensional (3D) measurements. Studies on rapeseed have mainly focused on its color detection, nutrition information extraction of rape canopy, leaf information studies, and plant modeling (Guan, 2007; Yuan et al., 2009; Zhang et al., 2006).

Recently, several methods have been developed to measure the 3D structure of entire objects in a non-destructive manner, including the use of a 3D digitizer, digital stereo photogrammetry, X-ray computed tomography, or phase-shifting projected fringe profilometry with some adaptation toward the quantification and visualization of 3D plant structures (Dornbushch, 2007). Among these methodologies, the 3D digitizer, also known

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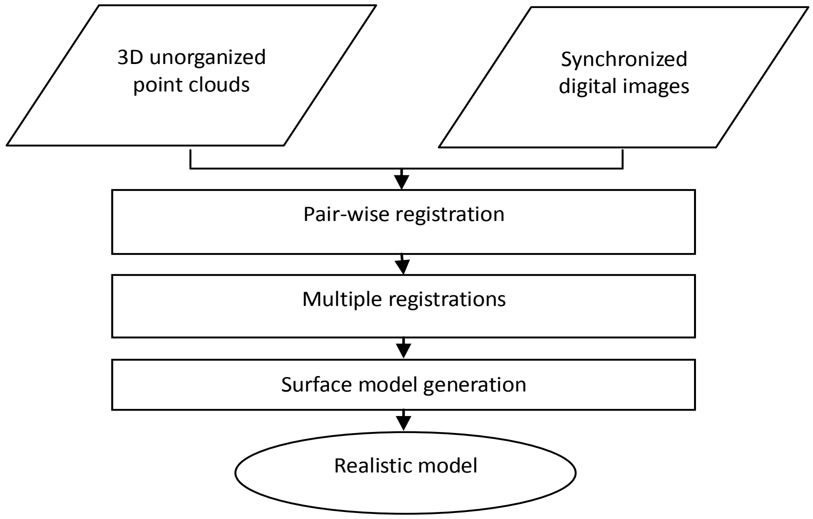


Figure 1. Flowchart of the proposed methodology.

as the 3D scanner, is a new device that can retrieve 3D data of a solid object by simply projecting light on to it. Compared with other methods, the advantage of using a digitizer is that it does not come into contact with the object, thus avoiding damage to the object being studied. Studies on the use of the 3D digitizer have mainly focused on maize (Ma et al., 2006), tomato (Masaaki and Yosuke, 2005), rice (Watanabe et al., 2005), and other plant models (Dornbushch et al., 2007).

However, measuring rapeseed using the 3D digitizer has rarely been reported. In the present study, the main objective is to evaluate the performance of using the 3D digitizer to generate the complex rapeseed model at maturity stage. The flowchart of the process is shown in Figure 1.

The process starts by taking 3D digitizer generated unorganized point clouds and image sequences from different viewpoints. Next, the unorganized points and the image sequence are used for the registration of all the data sets from all viewpoints, thus resulting in a complete rapeseed model. The registration approach includes pair-wise and multiple surface registration procedures that have been developed to combine all the scans into a common reference frame. The next procedure generates a surface model through a triangulated irregular network (TIN) using all the point clouds. Finally, the capabilities of the proposed system are demonstrated through real data sets. Quantitative and qualitative assessments of the results are also discussed.

MATERIALS AND METHODS

Experimental system and data acquisition

The experimental equipment consisted of a 3D digitizer (VIVID 910) from Konica Minolta, a rotatable platform on which the rapeseed was placed, a mechanical impulse device, a personal computer, and data acquisition software called polygon editing tool. The VIVID 910 digitizer (Figure 2) uses laser-beam light sectioning technology to scan work pieces using a slit beam. Light reflected from the work piece is acquired using a charge-coupled device (CCD) camera. Afterwards, the 3D data were created by triangulation in order to determine distance information. The laser beam was scanned using a high-precision galvanometric mirror; 640 × 480 individual points were measured per scan. In addition to distance data, this 3D digitizer was also used to acquire color image data. Using a rotating filter to separate the acquired light, the VIVID 910 digitizer created color image data for 640 × 480 points with the same CCD as that used for distance data. The software was used mainly to control the experimental setup and analyze the results.

Figure 2. The hardware system.

The rotatable platform was designed to capture data sets in a convenient way. It consisted of a planar patch, which was a stepper

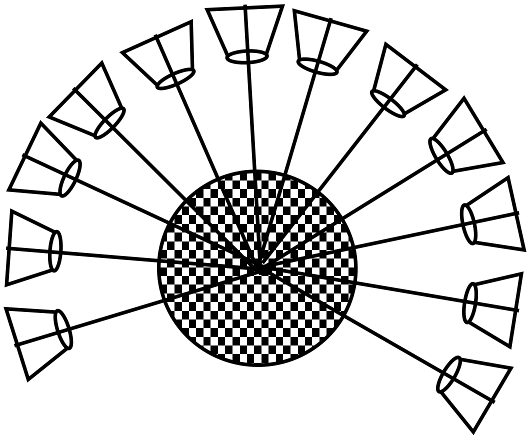
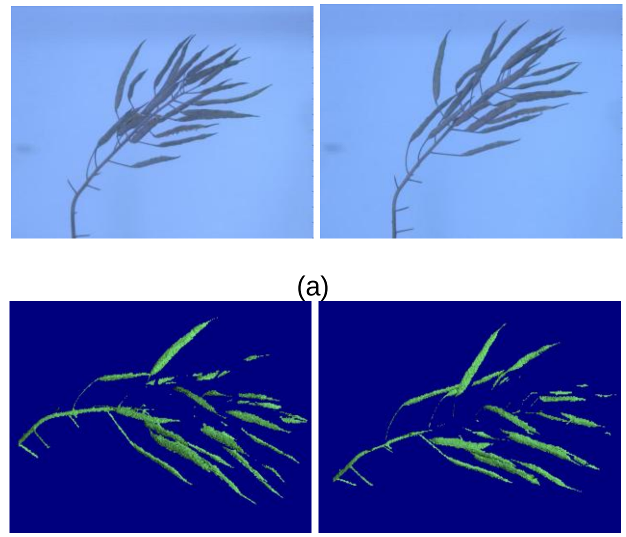


Figure 3. The methodology of data acquisition.



(a)

(b)

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17.698 51.676 -985.196
17.972 51.635 -984.406
20.504 53.751 -1025.505
20.803 53.749 -1025.467
17.412 51.393 -985.290
17.690 51.366 -984.757
20.206 53.454 -1025.548
20.505 53.452 -1025.516
16.849 51.144 -986.049
```

(c)

Figure 4. (a) The acquired digital images at certain viewpoints; (b) The corresponding 3D point clouds; (c) The coordinates of the 3D unorganized point clouds.

motor that can drive the platform to rotate. The object was placed on the center of the rotatable platform. Once the platform was driven to rotate at a given angle (that is, 12°), the digitizer captured the data sets one at a time. In this way, the sequential data sets of the object were acquired automatically (Figure 3). The data sets included 3D unorganized point clouds and their corresponding digital images. Some of these recorded from specific viewpoints are shown in Figure 4. The data sets from one viewpoint included one scan (3D unorganized point clouds) and one digital image, as shown in Figure 4a and b, respectively. Figure 4c presents the 3D coordinate values of the unorganized point clouds from one viewpoint, which would be used for later procedures.

Experimental Procedure

With the rotation of the rotatable platform at a given angle, one scan (represented by unorganized point clouds) and its corresponding digital image were taken at that viewpoint until the turntable finished one complete circle. Given that one scan was unable to represent the whole structure of the object, all the point clouds from different viewpoints were registered into one common reference frame. This process included two procedures, namely, pair-wise and seamless registration of multiple scans. To present the 3D architecture of the objects, we used the unorganized point clouds as well as the interrelations among all these unorganized points. Therefore, the next procedure involved building a surface model through the generated 3D point clouds of the entire rapeseed. Finally, a realistic 3D model of rapeseed at maturity stage was obtained, and its accuracy was also estimated.

Pair-wise registration

The registration of two scans played an important role in the rapeseed model generation. However, considering the complexity of the plants and the characteristics of unorganized point clouds, it is difficult to find two conjugate points among the unorganized point clouds from two adjoining viewpoints. According to the correspondent relations between one scan and the digital image at the same viewpoint, the model provided a promising way to find conjugate points for registration between the two scans at different viewpoints.

By finding conjugate points in the two adjoining digital images, we can locate conjugate 3D points between one adjoining scan pairs. Figure 5 shows the matched conjugate points from two adjoining digital images. According to the inner corresponding relations between digital image and the scan from one viewpoint, the conjugate 3D points were located between the two scans. Using more than three conjugate points in two 3D scans, the transformation parameters between individual pairs were computed effectively given by:

$$\begin{bmatrix} X_p' \\ Y_p' \\ Z_p' \end{bmatrix} = \begin{bmatrix} X_T \\ Y_T \\ Z_T \end{bmatrix} + SR(\Phi, \Omega, K) \begin{bmatrix} X_p \\ Y_p \\ Z_p \end{bmatrix} \qquad (1)$$

Where: X_p, Y_p, Z_p are the coordinates of a point from Scan 1;

X_T, Y_T, Z_T are three translations between the two reference frames; S is a scale factor between the two reference frames;

Figure 5. Match results of digital images. Red points represent the matched conjugate points from the two digital images.

$X_p^{'}, Y_p^{'}, Z_p^{'}$ are the coordinates of the transformed point with respect to the reference frame of Scan 2; $R(\Phi, \Omega, K)$ is the rotation matrix between the two reference frames as defined by the rotation angles Φ, Ω, K.

Seamless registration of multiple scans

As mentioned above, *n* pieces of scans of the rapeseed were obtained, which was essential in developing an effective approach to register all the *n* scans seamlessly. The *n* pieces were integrated using the transformation parameters acquired from the pair-wise registration. However, the error propagation of these parameters may possibly lead to error accumulation. In order to minimize such errors, we registered all the scans simultaneously in a multiple surface registration procedure.

The transformation parameters between individual pairs of surfaces were computed through pair-wise surface registration, which was introduced earlier. If the coordinate system of one scan was taken as the reference frame, other scans were transformed from their own reference frames into this common reference coordinate system using the transformation parameters between individual pairs. For one scan, two methods can be used to transform it into the common reference frame, namely, direct and indirect (Figure 6). For example, Scan 9 was integrated into the common reference frame, which was defined by Scan 1, using the pair-wise transformation parameters between Scan 9 and 1 directly. This integration was completed by transforming Scan 9 to 8 first, and then transforming it to Scan 7, and so on, until Scan 9 was transformed into the common reference frame of Scan 1. Ideally, the two transformed scans from Scan 9 to 1 using either the direct or indirect way should be identical. However, this was almost impossible to achieve due to error propagation.

In the present study, 30 scans and the corresponding digital image sequence were obtained. The average normal distances between individual pairs of original scans were less than 0.20 mm. As for the last scan, it was transformed into the common reference frame in two ways. The average distance between the two scans was 0.19 mm in the direct way, whereas that in the indirect way was 4.78 mm. This indicated that the effect of the error propagation was almost inevitable. Therefore, a methodology to refine the registration of *n* scans was developed. Its aim is to process all the scans simultaneously and solve all the transformation parameters of all individual scan pairs except for the transformation parameters between the first and the last scan with the initial transformation parameters acquired by Section A.

Assuming there were *m* scans in the research, Scan 1, 2, …, and *m*. The transformation function between each scan pair (e.g., Scan *i* and *i* + 1) could be expressed as follows:

$$SF_i = F_i(SF_{i+1}) \tag{2}$$

where SF_i is Scan *i*, SF_{i+1} is Scan *i* + 1, and F_i is the transformation function between these two scans.

As for point *P* $\{X_m, Y_m, Z_m\}$ in the last Scan *m*, it was transformed directly into the reference frame of Scan 1 to obtain the new coordinate values $\{X_m^{'}, Y_m^{'}, Z_m^{'}\}$; this is expressed in Equation (1). Meanwhile, the point was transformed into the common reference frame in the indirect way as described previously in order to obtain new coordinate values $\{X_m^{''}, Y_m^{''}, Z_m^{''}\}$; this is expressed in Equation (3). Given that $\{X_m^{'}, Y_m^{'}, Z_m^{'}\}$ and $\{X_m^{''}, Y_m^{''}, Z_m^{''}\}$ both represent the new coordinates in the reference frame of point $\{X_m^{''}, Y_m^{''}, Z_m^{''}\}$ from Scan *m*, the two coordinates should be identical as shown in Equation (4) below:

$$\begin{bmatrix} X_m^{'} \\ Y_m^{'} \\ Z_m^{'} \end{bmatrix} = \begin{bmatrix} X_{m,T} \\ Y_{m,T} \\ Z_{m,T} \end{bmatrix} + S_m R_m(\Phi_m, \Omega_m, K_m) \begin{bmatrix} X_m \\ Y_m \\ Z_m \end{bmatrix}, \tag{3}$$

Where: Xm, Ym, Zm are the coordinates of point *P* in Scan *m*; $X_m^{'}, Y_m^{'}, Z_m^{'}$ are the coordinates of the transformed point with respect to the common reference frame of Scan 1 in the direct way; $X_{m,T}, Y_{m,T}, Z_{m,T}$ are three translations between one scan pair, Scan *m* and Scan 1; $R_m(\Phi_m, \Omega_m, K_m)$ is the rotation matrix between the scan pair Scan *m* and Scan 1 as defined by the

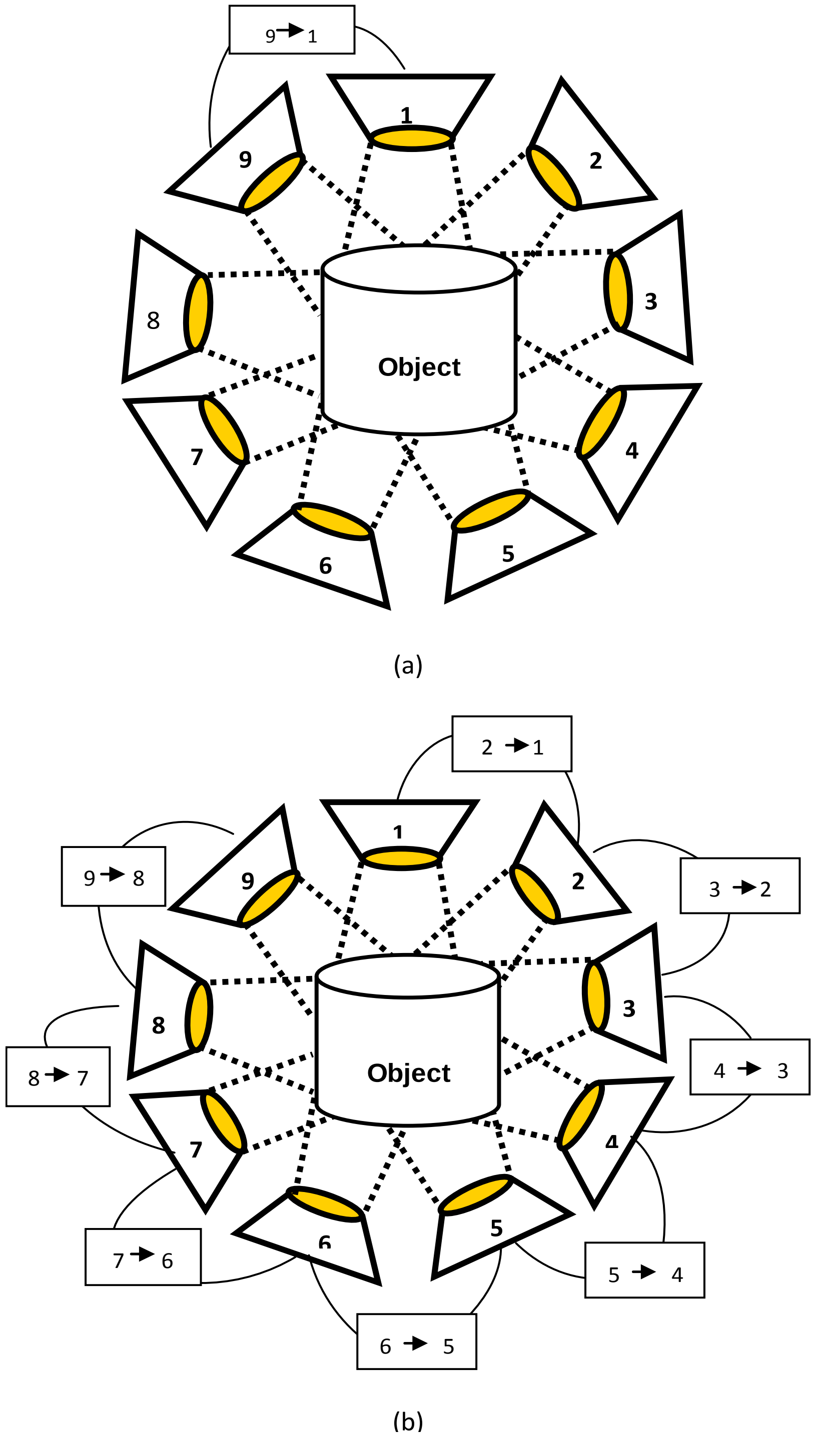


Figure 6. Scan 9 could be transformed into the common reference frame (scan 1) either in a direct way (a) or in an indirect way (b).

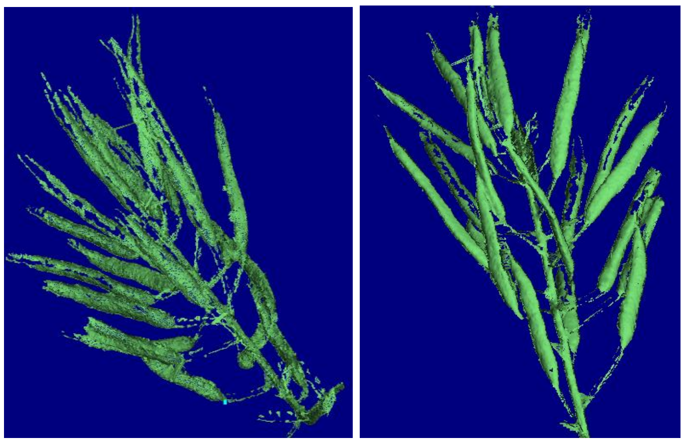
rotation angles Φ_m, Ω_m, K_m; and S_m is a scale factor between Scan *m* and Scan 1.

$$\begin{bmatrix} X_m^{''} \\ Y_m^{''} \\ Z_m^{''} \end{bmatrix} = R_1 R_2 \ldots R_{m-1} \begin{bmatrix} X_m \\ Y_m \\ Z_m \end{bmatrix} + \begin{bmatrix} X_{1,T} \\ Y_{1,T} \\ Z_{1,T} \end{bmatrix} + R_1 \begin{bmatrix} X_{2,T} \\ Y_{2,T} \\ Z_{2,T} \end{bmatrix} + R_1 R_2 \begin{bmatrix} X_{3,T} \\ Y_{3,T} \\ Z_{3,T} \end{bmatrix} + \cdots + R_1 R_2 \ldots R_{m-1} \begin{bmatrix} X_{m-1,T} \\ Y_{m-1,T} \\ Z_{m-1,T} \end{bmatrix} \quad (4)$$

In the above equation: X_m, Y_m, Z_m are the coordinates of point *P* in Scan *m*; $X_m^{'}, Y_m^{'}, Z_m^{'}$ are the coordinates of the transformed point with respect to the common reference frame of Scan 1 in the indirect way; $X_{i,T}, Y_{i,T}, Z_{i,T}$ are three translations between one scan pair, Scan *i* + 1 and Scan *i* (*i* values range from 1 to *m* – 1);

Table 1. The average normal distance between conjugate points after multiple registrations.

Scan pair	Average normal distances (mm) between matched points before multiple registrations	Average normal distances (mm) between matched points after multiple registrations
30-1	4.78	0.23



(a) (b)

Figure 7. The results between Scan 1 and the last scan (a) before and (b) after multiple registrations.

$R_i(\Phi_i, \Omega_i, K_i)$ is the rotation matrix between one scan pair, Scan *i* + 1 and Scan *I*, as defined by the rotation angles Φ_m, Ω_m, K_m (*i* values range from 1 to *m* - 1); and S_m is a scale factor between one scan pair, Scan *i* + 1 and Scan *i* (i values range from 1 to *m* – 1).

Equation (4) could be simplified as follows:

$$SF_1 = F_m(SF_m) \tag{5}$$

where SF_1 is the first scan (Scan 1), SF_m is the last scan (Scan *m*), and F_m is the transformation function between Scan *m* and 1 in the indirect way.

Considering all the transformation function between the combined scan pairs and the relations between the last and the first scan, the transformation parameters can be resolved simultaneously according to the following equations:

$$\begin{cases} SF_1 = F_1(SF_2) \\ SF_2 = F_2(SF_3) \\ \ldots \\ SF_i = F_i(SF_{i+1}) \\ \ldots \\ SF_{n-1} = F_i(SF_{i+1}) \\ SF_1 = F_m(SF_m) \end{cases} . \tag{6}$$

This procedure, used to resolve the transformation parameters, was called multiple registrations in our research. Meanwhile, the average normal distance among matched points before and after multiple registrations was also computed. The results are listed in Table 1. The registration results are also presented in Figure 7; Figure 7a shows the result without multiple registrations. There were some disclosures in Figure 7a, whereas there was almost no disclosure shown in Figure 7b, indicating that the multiple registrations were quite effective and necessary.

Surface model generation

The 3D point clouds of the rapeseed were acquired using the method introduced above. To determine the 3D shape of the rapeseed, we used just one set of feature points as well as the interrelations among these points. The TIN model is a simple way to build a surface from a set of irregularly spaced points, making it an attractive method due to its simplicity and economy. Using triangles, each piece of the mosaic surface is placed so as to ensure that it fits its neighboring pieces (that is, the surface is continuous). This is important because the surface of each triangle would be defined by the *z* coordinates of the three corner points, producing the flat appearance shown in Figure 8. In the TIN model, the points were shown in red and the lines connecting the corner points were shown in purple. The whole rapeseed model from different viewpoints is also presented in Figure 9, which shows that the model is complete and seamless.

RESULTS AND DISCUSSION

Rapeseed samples at maturity stage were collected and

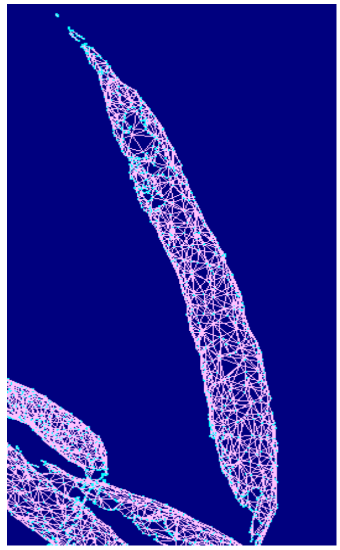


Figure 8. A rapeseed model at maturity stage by TIN.

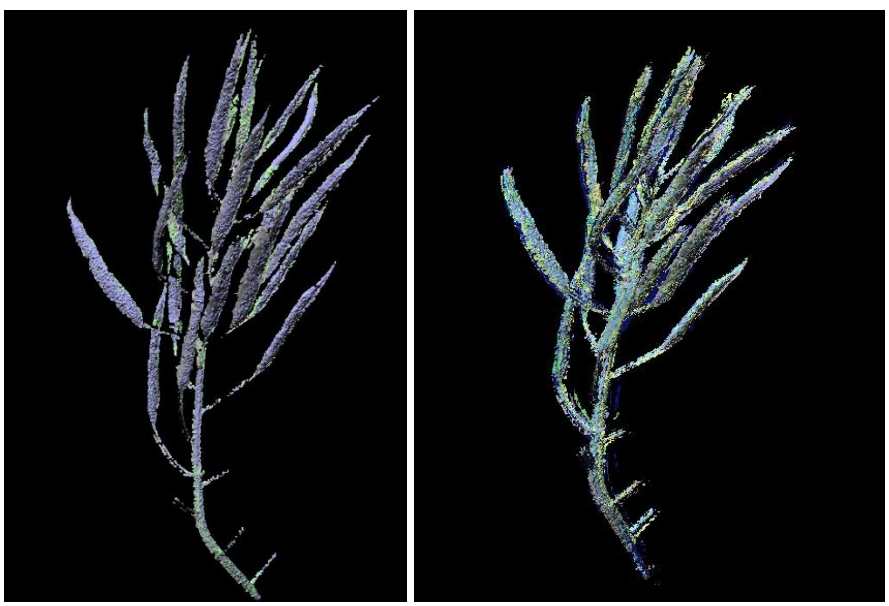


Figure 9. The rapeseed model from different viewpoints.

placed on the turntable controlled by the step motor. Meanwhile, a 3D digitizer was used to acquire data sets of the rapeseed from different viewpoints by rotating the rotatable platform. The proposed methodology was tested to evaluate its performance. In the application, it was applied to reconstruct the surface of one part of a mature rapeseed. A surface model of this part was produced by combining all the scans acquired from different viewpoints. The reconstructed results were also checked to assess their accuracy.

Quantitative assessments of the results

After conducting multiple surface registrations, all the scans were transformed into a common reference frame, which was defined by the first scan, and combined to represent one entire rapeseed model. The average normal distances between the matched points after multiple surface registrations were used as a measure to quantify the quality of registration among all the registered scans. For example, the multiple surface registrations were performed using 30 scans that have problems of disclosure caused by error propagation of the pair-wise transformation parameters. The experimental results are shown in Table 1, which indicates that the average normal distances between the two scans were less than 0.3 mm after simultaneous registration. However, that value was 4.87 mm before the multiple registrations. The results also demonstrated that all the scans were well combined to a 3D surface model through the multiple surface registration procedure. In addition, the model did not suffer from the error propagation of the pair-wise transformation parameters.

Qualitative assessments of the results

Qualitative assessments of the results of the 3D model were used to confirm the efficiency of the proposed methodology. The assessments were carried out by visually checking the overlapping areas between the first and the last scans in the combined surface model after multiple surface registrations (Figure 7). Specifically, a cross-section of the resulting rapeseed model revealed the quality of registration between scans after the multiple surface registrations. The examination provided information on how well the scans acquired from different viewpoints were registered and combined.

CONCLUSIONS AND FUTURE WORK

The current paper presents a detailed methodology of the automated 3D morphological generation of rapeseed at maturity stage using a 3D digitizer. On the basis of the results of the present study, it can be stated that (1) the 3D digitizer can be used to implement reconstruction of complex organs of plants and 3D shape, and (2) multiple surface registrations are essential for the generation of the 3D shape of rapeseed, leading to better representation and description results compared with other methodologies.

Our future work aims to focus on the following two main aspects: (1) investigating more rapeseed organs and analyzing the mathematical model of these organs to express them through computer graphics, and (2) integrating the generated 3D shape of the rapeseed organs into an L-system to yield a vivid virtual plant that can represent the 3D growth of rapeseed across all growth stages.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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Full Length Research Paper

Nutritive value assessment of three range plants by chemical and *in vitro* gas production techniques

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This study was conducted in order to measure the nutritional value, as ruminant food, of three range plants (*Dactylic glomerata, Onobrychis sativa* and *Setaria galauca)*, that were collected completely random from north of Iran (Guilan). Chemical analysis and *in vitro* gas production technique were used as the base for that evaluation. The chemical composition in term of ash, ether extract (EE), crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), non-fibrous carbohydrates (NFC), nitrogen free extract (NFE), crude fiber (CF) and organic material (OM) have significant differences (p < 0.05) among *D. glomerata, O. sativa* and *S. galauca*. CP were ranged from 8 (*S. galauca*) to 24% (*O. sativa*), and ADF from 37.8 (*O. sativa*) to 67.45% (*S. galauca*). Amount of fermentable fraction (b) were ranged from *D. glomerata* (68.53 ml), *O. sativa (*66.09 ml) and *S. galauca* (49.5 ml). Potential gas production (a+b) were ranged from *D. glomerata* (63.89 ml), *O. sativa (*63.39 ml) and *S. galauca* (47.4 ml). This is due to their high content of CP and low content of ADF. Therefore, according to the potential gas production performance, *D. glomerata* was ranked higher than the two other plants. The higher values obtained for the potential gas production in the *D. glomerata* and *O. sativa* indicate a better nutrient availability for rumen microorganisms. Most of chemical compounds have significant correlation with gas production factors such as fermentable part fraction (b) and potential gas production (a+b).

Key words: Range plant, nutritive value, gas production, chemical, correlation.

INTRODUCTION

More than 90 of 164 billion ha of Iran are allocated to rangelands area as an important part of livestock feed (above 80%) (Arzani et al., 2004). It is well known that forages have an important role in ruminant animal in terms of providing energy, protein and minerals as well as fibre for chewing and rumination (Kamlak, 2010). *Dactylic glomerata* and *Setaria galauca* belong to the Gramineae family and *Onobrychis sativa* belongs to the Leguminosae (Fabaceae) family. They are widely spread in rangelands of Iran and are grazed well by ruminants especially by small ruminants. Holchek et al. (1986) results showed that the amounts of crude protein (CP), acid detergent fiber (ADF), and neutral detergent fiber (NDF) for *O. sativa* are 21.2, 52.3 and 47%, respectively. Jancik et al. (2010) results showed that the amounts of CP, NDF and ADF for *D. glomerata*

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are 13.1, 56.3 and 31.4%, respectively. Recently, some researchers have used the *in vitro* gas production technique to evaluate the fermentation kinetics of ruminant feedstuff (Mesgaran and Mohammadabadi, 2010; Chaji et al., 2010; Kamlak, 2010). In the gas method, kinetics of fermentation can be studied by simply reading the increase in gas production at a series of chosen time intervals and using the exponential equation $P = a+b\ (1 - e^{-ct})$ (Ørskov and McDonald, 1979). The present study was done to evaluate the nutritive value, by the use of *in vitro* incubation techniques with rumen fluid (gas production) and chemical analysis, for *D. glomerata, O. sativa* and *S. galauca* range plants.

MATERIALS AND METHODS

Three species of range plants, were grown naturally on the rangeland of Iran, especially north of Iran (Guilan), which receive a total annual precipitation of 500 to 1100 mm (Moghaddam, 2009). Forage samples from each herbaceous range plants were randomly taken, in three repeats (each replication were a compound of 5 samples of each species) and dried at room temperature (25 to 30°C) for 3 weeks, ground to pass through a 1 mm sieve, well mixed and stored frozen at (-20°C) in sealed nylon bags for later analysis and evaluation. Chemical analysis of forage samples were performed according to AOAC (2005), and contents of NDF and ADF were determined by the method of Van Soest et al. (1991).

The method of Menke et al. (1979) was used to determine the rate of gas production during 96 h incubation (0, 2, 4, 6, 8, 12, 24, 48, 72 and 96 h). Digestion kinetics were calculated according to the exponential equation $P= a+b\ (1 - e^{-ct})$ of Ørskov and McDonald (1979), where P (ml) were defined as gas production at time (t), a (ml) was the initial gas production, b (ml) was the gas production during incubation, a+b (ml) was the potential gas production and (c) (ml/h) was the fractional gas production. The forage samples (0.200 g dry weight) were incubated in triplicate in rumen fluid, in calibrated 100 ml glass syringes at 39°C following the procedure of Menke and Steingass (1988).

The rumen fluid was collected from three rumen fistulated sheep's (same age and weight) before morning feeding (17 h after the last feed) and was homogenized and strained through 100 µm nylon cloth into a warm flask (39°C) filled with CO_2. The fistulated sheeps were fed twice daily with a diet containing hay (60%) and concentrate (40%). A total of 30 ml of medium, consisting of 10 ml of rumen fluid and 20 ml of bicarbonate-mineral-distilled water mixture (1:1:2 by vol.), was pumped with an automatic pipette into the warmed syringes containing the samples (200 mg) and into the blank syringes. Gas production from the forage sample was calculated by subtracting the volume of gas produced from the blank with or without the addition of forage, depending on treatment. The difference in gas production as a result of treatment was calculated and expressed as a proportion of that for the untreated sample (that is, % increase).

$$DMD\% = 83.54 - 0.824(ADF\%) + 2.626(N\%) \text{ (Oddy et al., 1983)}$$

$$NE_{(Mcal/lb)} = [2.20 + (0.0272 * Gas) + (0.057*CP) + 0.149 * CF)] / 14.64 \text{ (Menke et al., 1988)}$$

$$OMD\ (\%) = 0.9991\ (G_{24h}) + 0.0595\ (CP) + 0.0181\ (CC) + 9 \text{ (Menke and Steingass, 1988)}$$

$$ME_{(MJ/kgDM)} = 0.157\ (G_{24h}) + 0.0084\ (CP) + 0.022\ (EE) - 0.0081(CC) + 1.06 \text{ (Menke and Steingass, 1988).}$$

$$SCFA_{(mmol)} = 0.0222(G_{24h}) - 0.00425 \text{ (Makkar, 2005)}$$

Where: G_{24h} is 24 h net gas production (ml/g DM), CC, CP, EE and CF are crude ash, crude protein, ether extract and fat, respectively (% of DM).

Means of the studied parameters were subjected to an analysis of variance (ANOVA) test, and Duncan test at the 95% confidence level by SPSS soft. Correlation analysis was used to establish the relationship between chemical composition and *in vitro* gas production parameters.

RESULTS

The chemical composition percentage as DM bases and correlation of chemical parameters for three range plants are presented in Tables 1 and 2, respectively. Ash, EE, CP, ADF, NDF, non fibrous carbohydrates (NFC), nitrogen free extract (NFE), crude fiber (CF) and organic material (OM) has significant differences ($p \leq 0.05$) among *D. glomerata, O. sativa* and *S. galauca*. CP was ranged from 8 (*S. galauca*) to 24% (*O. sativa*) and ADF from 37.8 (*O. sativa*) to 45.67% (*S. galauca*).

In vitro gas production of rumen gas from the three range plants is presented in Tables 3 and 4. Amount of gas production in all treatments has on an uptrend and it increases. Amount of produced gas (Ml/200 mgDM) in three species at all times of incubation has significant differences ($P \leq 0.05$). The rate of fermentation fraction (c) was significantly ($p < 0.01$) higher in *S. galauca* than in *O. sativa* and *D. glomerata*, but fraction (b) and fraction (a+b) were significantly ($p < 0.01$) higher in *O. sativa* and *D. glomerata* than in *S. galauca* (Table 3).

The rank order in terms of potential gas production performance in 0 to 24 h of incubation are *S. galauca* > *O. sativa* > *D. glomerata* and in 24 to 96 h time of incubation is *D. glomerata* > *O. sativa* > *S. galauca* (Table 4 and Figure 1).

There were significant correlations between the fermentation parameters and the chemical composition of three species (Table 5). Significant correlations were found for all gas parameters, except NE, SCFA and ME with ash. No significant correlation was found, except OMD and NE, with CF content. Negative correlations were detected between all gas parameters, except SCFA

Table 1. Chemical composition of three range plants as percent DM bases.

Treatment	CP	EE	CF	ASH	ADF	NDF	DMD	NFE	NFC	TDN	OM
S. galauca	7.95^{c}	4.06^{a}	31.00^{a}	4.23^{b}	45.67^{a}	73.93^{a}	49.25^{c}	49.7^{a}	38.09^{a}	54.93^{c}	95.77^{a}
D. glomerata	12.16^{b}	3.47^{a}	28.13^{b}	6.09^{ab}	41.81^{b}	72.78^{b}	54.19^{b}	45.24^{b}	35.56^{a}	55.71^{b}	93.00^{b}
O. sativa	23.95^{a}	2.51^{b}	12.43^{c}	7.00^{b}	37.78^{c}	53.84^{c}	62.47^{a}	51.16^{a}	29.667^{b}	68.59^{a}	93.91^{ab}

Columns having different superscripts are significantly different ($p < 0.05$).

Table 2. Correlation coefficient (r) between chemical composition parameters in three range plants.

Pearson correlation	CP	EE	CF	ASH	ADF	NDF	DMD	NFE	NFC	TDN	OM
CP	1.00										
EE	-0.87**	1.00									
CF	-0.99**	0.81**	1.00								
ASH	0.37^{ns}	-0.44^{ns}	-0.29^{ns}	1.00							
ADF	-0.96**	0.86**	0.92**	-0.49^{ns}	1.00						
NDF	-0.97**	0.82**	0.99**	-0.18^{ns}	0.89**	1.00					
DMD	0.991**	-0.871**	-0.97**	0.42^{ns}	-0.99**	-0.95**	1.00				
NFE	0.49^{ns}	-0.40^{ns}	-0.58^{ns}	-0.56^{ns}	-0.31^{ns}	-0.65^{ns}	0.41	1.00			
NFC	-0.95**	0.798**	0.936**	-0.56^{ns}	0.90**	0.89**	-0.93**	-0.31^{ns}	1.00		
TDN	0.97**	-0.82**	-0.99**	0.18^{ns}	-0.896**	-1.00**	0.945**	0.65^{ns}	-0.89**	1.00	
OM	-0.37$^{\mathbf{ns}}$	0.44$^{\mathbf{ns}}$	0.29 $^{\mathbf{ns}}$	-1.00**	0.49$^{\mathbf{ns}}$	0.18$^{\mathbf{ns}}$	-0.43$^{\mathbf{ns}}$	0.56$^{\mathbf{ns}}$	0.56$^{\mathbf{ns}}$	-0.18$^{\mathbf{ns}}$	1.00

*$p < 0.05$; **$p < 0.01$; ns = Non significant.

Table 3. Parameters of *in vitro* gas production in three range plants (defined by the equation: $p = a + b\ (1 - \exp^{-c\ t})$.

Treatment	Incubation time								
	a	b	c	a+b	DMD	OMD	SCFA	ME	NE
S. galauca	-2.08^{b}	49.5^{b}	0.09^{a}	47.42^{b}	55.20^{b}	55.43^{b}	9.38^{b}	7.55^{b}	6.11^{a}
D. glomerata	-4.68^{a}	68.53^{a}	0.04^{b}	63.85^{a}	69.24^{a}	64.3^{a}	10.65^{a}	8.52^{a}	6.3^{a}
O. sativa	-2.71^{b}	66.09^{a}	0.04^{b}	63.39^{a}	69.06^{a}	65.92^{a}	9.3^{b}	7.6^{b}	4.62^{b}
SEM	0.2	0.5	0.27	0.34	0.39	1.36	0.21	0.21	0.12
Significant	**	**	**	**	**	**	**	*	**

c = Rate constant of gas production during incubation (ml h^{-1}); a = gas produced from soluble fraction (ml); b = gas produced from insoluble but fermentable fraction (ml); a+b = potential gas production (ml); Columns having different superscripts significantly ($p < 0.01$).

and ME, with ADF content ($P < 0.01$) (Table 5).

DISCUSSION

The results showed that there were significant variations in chemical composition and gas production characteristics of three range plants. Amount of CP in *S. galauca, D. glomerata* and *O. sativa* is 7.65, 12.1 and 23.95%, respectively. Theminimal CP content of DM for maintenance of sheep has been indicated by Milford and Haydock (1965) to be 7.2%. However, it was suggested to be at least 8.9% CP in plant material. The CP value in the present study plants were mostly well above the recommended levels by Milford and Haydock (1965) and NRC (1990), suggesting that they might maintain animals. On the other hand, the CP of *S. galauca* is fitted for sustain sheep if used as the only sources of feed. Range land forages are composed of structural and non-structural constituents. Rezayi (2004) reported that amount of CP belonged to theleaf:stem ratio and causes an increase in plant protein thus this reason amount of CP in *O. sativa* is more than that of *S. galauca* and *D. glomerata*. The leaves of *O. sativa* is phyllde form, but *S. galauca* and *D. glomerata* do not have phyllde leaves (Gramine family) and the leaf:stem ratio is low.

The surface of a leaf will be increased growing rate, DM and protein content as a result of increasing number of photosynthetic organ per unit of leaf surface (Hattab and Harb, 1990). The results showed that the ADF

Table 4. Rumen gas production (ml/200 mg DM) from three range plants under different times.

Treatment	Incubation time								
	2	4	6	8	12	24	48	72	96
S. galauca	3.74[a]	9.67[a]	18.12[a]	24.38[a]	32.83[a]	39.00[b]	44.69[c]	47.94[c]	49.08[c]
D. glomerata	2.12[b]	4.16[c]	7.10[c]	10.69[c]	21.46[b]	44.31[a]	56.40[a]	59.91[a]	60.98[b]
O. sativa	2.44[b]	5.11[b]	8.53[b]	12.91[b]	20.63[c]	38.67[b]	53.45[b]	57.68[b]	61.42[a]
SEM	0.21	0.27	0.36	0.03	0.42	0.73	0.89	0.4	0.24
Significant	**	**	**	**	**	**	**	**	**

Columns having different superscripts are significantly different (p < 0.05).

Table 5. The correlation coefficients (r) between the chemical composition and gas production parameters.

Pearson correlation	CP	EE	CF	ASH	ADF	NDF
a	0.03[ns]	0.09[ns]	-0.14[ns]	-0.67*	0.22[ns]	-0.27[ns]
b	0.61[ns]	-0.62[ns]	-0.52[ns]	-0.74*	-0.79*	-0.44[ns]
c	-0.70*	0.69*	0.61[ns]	-0.72*	-0.86**	0.54[ns]
a+b	0.68*	-0.67*	-0.59[ns]	0.72*	-0.85**	0.54[ns]
OMD	0.79*	-0.75*	-0.72*	0.68*	-0.92**	-0.66[ns]
DMD	0.69*	-0.68*	-0.60[ns]	0.72*	-0.85**	-0.53[ns]
SCFA	-0.31[ns]	0.16[ns]	0.42[ns]	0.54[ns]	0.07[ns]	0.50[ns]
ME	-0.22[ns]	0.08[ns]	0.33[ns]	0.59[ns]	-0.03[ns]	0.41[ns]
NE	-0.93**	0.76**	0.96**	-0.07[ns]	0.82**	0.99**

c = Rate constant of gas production during incubation (% h^{-1}); a = gas produced from soluble fraction (ml/0.200 g OM); b = gas produced from insoluble but fermentable fraction (ml/0.2 g OM); a+b = potential gas production (ml/0.200 g OM); *P < 0.05, **P < 0.01***P < 0.001; ns = non significant.

content was ranged from 37.8 (*O. sativa*) to 67.45% (*S. galauca*). The leaf:stem ratio decreased in the fibre content and an increased level of protein in the plants (Aaron et al., 2005). Amount of CP, NDF and ADF of *O. sativa* is 25, 53.8 and 37%, respectively. This result is in agreement with findings by Holchek et al. (1986) who reported 21.2, 52.3 and 47%, respectively. Arzani et al. (2006) reported that CP of legume family is more than gramine family and ADF is lower. However, in contrast to our results, Kaplan (2011) showed lesser CP (16.9%) and same ADF and NDF according to chemical compounds for the *O. sativa.* Jancik et al. (2010) detected that amount of CP (13.1%),

NDF (56.3%) and ADF (31.4%) contents are in agreement with present findings in the *D. glomerata*. Results of Bostan et al. (2010), in *D. glomerata* showed that the amount of ADF (31%) is lesser than that of present findings, CP (18%) is more than that of present findings and NDF (71%) is similar with that of present findings. The highest amount of NDF and ADF are caused to decreasing dry matter digestibility (DMD) and increasing plant fiber (van Soest et al., 1991; Mohanty et al., 2000; Beakou et al., 2008). The result showed that the highest level of gas production occurred after 16 to 24 h incubation. This stage of incubation in ruminants showed that fermentation of forage is maximal. It related to the ration and its constituents, and for more readily digestible carbohydrates is 12 to 16 h and for less digestible carbohydrates is 24 to 96 h (Kinan and Krishnamoorthy, 2007; Vanic et al., 2008).

The most of fermentable fraction (b) and the potential gas production (a+b) in 0 to 20 h of incubation time belonged to *S. galauca* and after 20 h of incubation time, belonged to *O. sativa, D. glomerata* and *S. galauca,* respectively. It may be due to their content of ADF, NDF and protein, whereas the potential gas production (a+b) is associated with degradability of feed (Kamalak et al., 2005). Therefore, the higher values obtained for the potential gas production in the *O. sativa* indicated a better nutrient availability for rumen microorganisms. ADF and EE correlation with fraction (b) and (a+b) were negative but ash and CP correlation with fraction (b) and (a+b) were positive. This result is consistent with findings of Frutos et al. (2002). ADF were negatively correlated with most of the estimated parameters. This result is in agreement with the findings of Abdulrazak et al. (2000) and Kamalak et al. (2004).

The negative correlation between potential gas production and ADF may be due to the reduction of microbial activity from increasingly adverse environmental conditions as incubation time progress. CP was positively correlated with the rate of fermentation

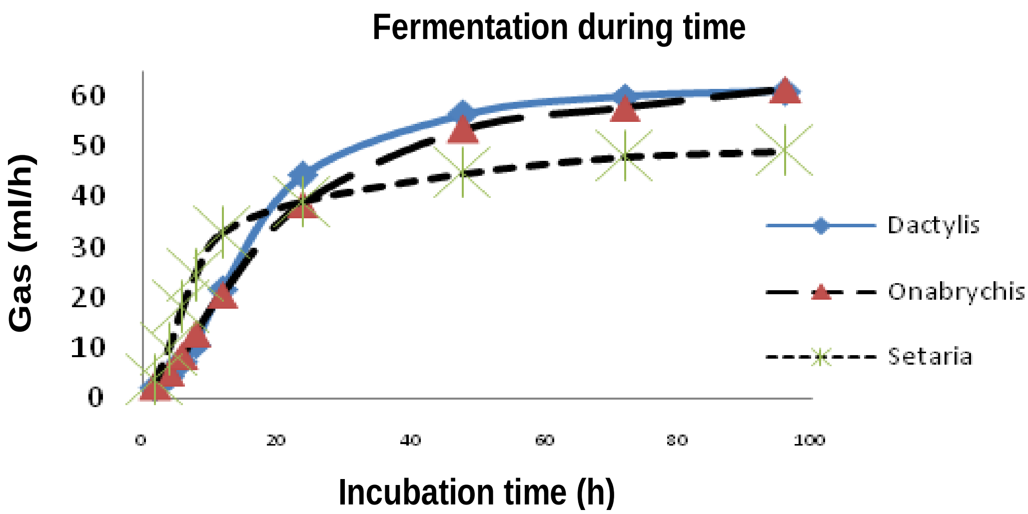

Figure 1. Cumulative gas production of three range plants.

fraction (c), fraction (b) and fraction (a+b). These findings were supported by Kamalak et al. (2004). Correlation relationship of chemical composition with gas production kinetics and some estimated parameters are in agreement with findings of Kaplan (2011). The chemical characteristics correlation showed that CP was negatively correlated with EE, ADF, CF, and NDF. The high amount of a leaf could be increased growing rate, DM and protein content and decreased ADF, CF, and NDF as a result of increasing number of photosynthetic organ per unit of leaf (Hattab and Harb, 1990).

Conclusion

The results revealed that the *O. sativa, D. glomerata* and *S. galauca* could be used such as forage for livestock, respectively.

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Full Length Research Paper

Effects in mechanical properties and structure of the soil after tillage with rotary paraplow

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At present great emphasis is being put on soil preparation tools which conserve the initial conditions of soil structure, preventing erosion and preserving soil for future generations. A new conservational tillage tool – the rotary paraplow, it were carried out studies addressing the changes in structure and in mechanical properties of soil after tool operation. Dimensional analysis has been used as methodology since it calls for a judicious choice of dependent and independent variables of the studied phenomenon, followed by a method of algebraic calculation used to determine the components and essential combinations among the parameters, reaching the determination of the minimum number of repetitions. The results have shown that Rotary Paraplow generated a well-prepared subsurface cultivation furrow. The evaluation of the operational tests for the dimensionless graphs has determined that the best setting is that in which the tool works with forward speed of 0.36 m.s^{-1}, rotation of 514 min^{-1} and depth of 150 mm. The action of this new tool can be considered as conservation tillage because all parameters are within limits imposed by the literature on the subject in order to consider soil tillage as conservational.

Key words: Soil dynamics, dimensional analysis, paraplow.

INTRODUCTION

Many studies have been carried out seeking to propose new tools for soil preparation, and great efforts have been made in order to experimentally prove their real advantages and operating configurations. The preparation of agricultural soil is a mechanical process that may lead to the cutting, overturning and inversion of the layer of soil, through the actions of the active organs of the implements, seeking to provide minimum conditions for developing crops (ASAE, 1997).

Conservational soil tillage reduces the intensity level of soil preparation, retaining wastes and forming a surface vegetation cover, which may lead to an accumulation of organic matter on the surface, producing a layer from 10 to 15 cm, from which the greatest benefits are an improvement in the stability of soil's structure, while the improved physical qualities of the soil (Carter, 2004) may also increase the association of minerals and organic particles, resulting in the formation of organo-mineral

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micro-structures, and in certain situations an increase in the biological activity of soil (Temesgen et al., 2012). Furthermore, the macro-fauna complements some levels of soil preparation under the ground, and although many studies into the effects of tillage systems on the soil organisms make comparisons between the two extremes (without tillage and conventional cultivation), it is known that intermediate forms of soil tillage produce intermediate effects (Kladivko, 2001).

Chang (2010) developed a rotary type, which is a fusion of a vertical milling cutter and a conventional Paraplow. The vertical cutter allows having a better mobility in the subsurface and thus greater penetration of water, while the Paraplow only affects the soil in the horizontal position without inverting it, keeping waste on the surface of cultivation soil and forming a cover.

The rotary paraplow is a new tool for soil preparation that performs a good sub-surface preparation of the planting strip, while hardly affecting the surface (Albiero et al., 2011a). According to the SSSA (2005), the paraplow is a type of non-inversive implement for subsoiling (conservational) designed to increase the force of structural breaking of the soil sideways using wide subsoiling surfaces crosswise to the movement and angled laterally so as to raise the soil. The soil cultivated with the paraplow is fractured into zones of weakness, in other words, the soil is moved around and not inverted (Erbach et al., 1992).

The rotary paraplow consists of 3 paraplow tines separated by 120°, and they have the same characteristics as paraplow. These blades are welded onto a circular upper support, drilled specifically for cutter supports, seeking to increase the rigidity of the tool's structure, while the lower side blades have been extended to a central supporting tube with a diameter between 20 and 60 mm. This tube also has the function of carrying fertilizer to the planting strip being tilled.

In the strips cultivation the habitat of the soil's flora and fauna is only partially destroyed (Geissen et al., 2003; Trevini et al., 2013). Cultivation in strips influences the total porosity of the soil, the apparent density, and particularly the rate of infiltration in relation to direct planting; this is noticeably higher (Geissen et al., 2003).

Maciel and Albiero, (2007) tested several models of rotary paraplows, a vertical rotary hoe and a conventional paraplow, in a soil bin and in the field. In the soil bins tests it was found that the rotary paraplow has a considerable vertical force, allowing automatic penetration due to their geometry, which acts on soil like a thread, thus doing away with the need for external force for their penetration.

In this context, the methodology of dimensional analysis is ideal since Maciel (1993), in his doctorate thesis, proved that dimensional analysis:

"Establishes qualitatively the identification of the parameters that influence the phenomenon of soil preparation, while also determining quantitatively the occurrence of inter-relationship of the parameters set for this phenomenon."

Albiero et al. (2011b) asserts that dimensional analysis captures the differences between treatment with great accuracy and less work. The dimensionless graphs make the differences visible and fit for calculation through the differentiation of the angular coefficients of the straight lines that represent the specific behaviours, while the method in itself optimizes the necessary quantity of data for obtaining perceptible responses, generating graphs with the minimum number of points and no requirements of normality. The collected data are treated through Pi-terms that are invariable non-dimensional factors, that is to say, they show constant behaviour as a function of the specific characteristics of the phenomenon, which represents inter-related behaviours among parameters that are linearly independent, allowing the proportional quantification of the variations as a function of their properties, which generates different straight lines (different angular coefficients), considerably easing the interpretation of the results.

The aim of this paper is to evaluate and describe the new conservational tillage tool – the rotary paraplow – in order to discover by experiment its best operational configuration and to carry out studies addressing the changes in structure and in mechanical properties of soil after the operation of the tool.

MATERIALS AND METHODS

Rotary paraplow

The rotary paraplow used in this experiment, Figure 1, consists of three paraplow tines separated by 120°. The technical recommendations of the soil dynamics science described in the literature were followed to improve the conservational performance: The optimized rotary paraplow has a set of three blades, each one with two mounted blades, with the lower blade welded at an oblique angle in relation to the upper one, and attached to the support. The lower blade has two inclination angles, one on the vertical plane (leading angle) and the other one on the horizontal plane (cutting angle).

The upper blade, attached to the support, has a 30° cutting angle, following Tupper et al. (1998) suggestion, while the lower blade is welded onto the upper and to the central tube, and has three different angles: one on the horizontal plane and the other one on the vertical (angle of advance and leading angle, respectively), both at 45° (Gill and Vanden Berg, 1968; Upadhyaya et al., 2009); the third angle derives from the blade's inclination in relation to the oblique plane where it is placed (due to the angles of the horizontal and vertical planes) and measures 15° (Koolen and Kuipers, 1983). This configuration has the purpose of shearing the soil through a stress composition that raises it, causing the rupture of the body of soil at the natural rupture angle, thus reducing resistance to stress. These blades are welded onto an upper circular support with an appropriate hole, like those of mechanical scythes. To increase the tool's rigidity, the lower side blades were extended to a central supporting tube with a 25 mm diameter (Figures 1 and 2).

The rotary paraplow was pulled by a Bertolini 318 mini-tractor, loaned by the company Argos Tech, which runs on a single-cylinder

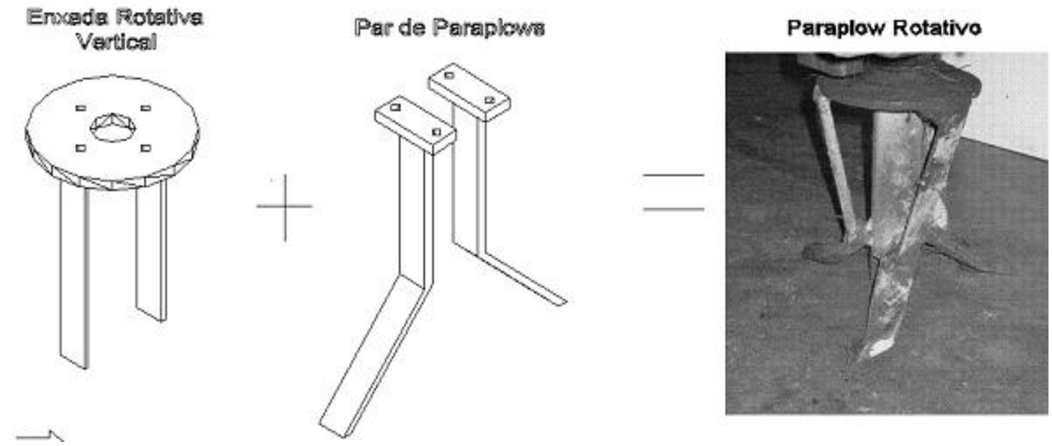


Figure 1. Conceptual idea of rotary paraplow.

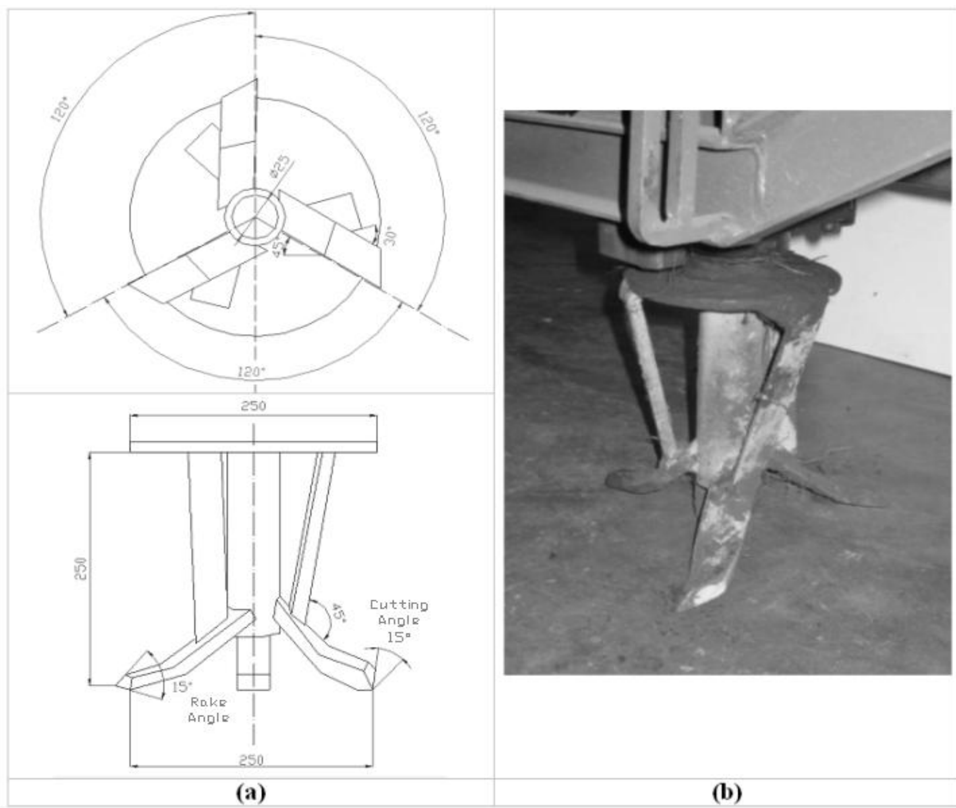


Figure 2. (a) Technical drawing of the rotary paraplow; (b) Rotatory paraplow used in the experiment (Albiero et al., 2011a).

diesel engine that develops 12 HP (8.95 kW) rated power at 3000 min^{-1}, with two speeds for the PTO (power take off) (V1 = 600 min^{-1} V2 = 900 min^{-1}), coupled to a tool-carrying chassis fitted with a conical reduction gear, with reduction of 1.75: 1.

In this experiment, it was used as the 1st and 2nd gears, which develop a speed of 0.36 and 0.7 m.s^{-1} on a concrete track. Rotations 1 (600 min^{-1}) and 2 (900 min^{-1}) were used, considering that the reduction ratio of the transmission of the rotary paraplow has the following rotations on the tool: 1 (342 min^{-1}) and 2 (514 min^{-1}).

Characteristics of the test area

This research has been developed in the Experimental Field of the Agricultural Engineering Faculty / University of Campinas, which has the following geographical coordinates: Latitude: 22°48'57" South, Longitude 47°03'33" West, and an average elevation of 640 m. The soil where the experiment was conducted is typical of the region of Campinas, São Paulo State, Brazil; in the Oxisol ortose case (Freire, 2006). Its granulometry is: 60% clay, 19% silt , 18%

Table 1. Combination of the dependent variable of the experiment.

Treatment	Vm	Rot	Pr
E111	1	1	1
E112	1	1	2
E121	1	2	1
E122	1	2	2
E211	2	1	1
E212	2	1	2
E221	2	2	1
E222	2	2	2

Obs: Vm1= 0.3; Vm2= 0.7; Rot1= 342 rpm; Rot2= 514 rpm; Pr1= 150 mm; Pr2= 200 mm.

sand and 3% organic matter. The last planting took place 7 years prior to the experiment, with corn (*Zea mays*). The area proved to be compacted, with a cone index above 1500 kPa, and is the upper part of a slope with a 3% gradient, infested with guinea grass (*Panicum maximum* Jacq.) and *Brachiaria decumbens* Stapf. (Kissmann, 2000).

In order to choose the most relevant parameters, determination of the experimental procedures, and to prioritize planning elements, it was used the dimensional analysis methodology, which starts with a judicious choice of dependent and independent dimensional variables of the studied phenomenon, followed by a method of algebraic calculation to determine the essential components and combinations among the parameters, finalizing with the determination of the minimum number of repetitions.

In this context, and based on studies carried out under the light of the existing theories and literature concerning a conservational appraisal of soil-tilling machines, the following variables were selected: Cohesion (c) and internal friction angle (ϕ) of the soil seeking to obtain knowledge of the dynamic properties of the soil and the alterations sustained; original cone index (CI0) and cone index after the operation in the crack areas (CIF) of the area prior to the operation for inference of resistance to root penetration and level of de-compacting; weighted mean diameter of wet aggregates (WMD) to evaluate the degree of stability of the aggregates faced with erosion; apparent density (γ) of the soil to evaluate the changes in soil compaction. Lower width (LW) of the planting strip (planting strip well prepared; width fissures of the region (WF) of the planting strip (planting strip turned); width of raising (WR) of the planting strip (planting strip turned); raised area (AR) (plaintiff strip turned); water content (U). All these parameters (considered as independent variables for dimensional analysis) varied freely and had their data gathered in experiments.

Experimental outline

The experimental outline for this research sought to evaluate the rotary paraplow in all possible operational combinations, so as to achieve a complete characterization of the de-compacting of the soil it performs. Therefore, a totally random experimental project was followed, defined by Cochran and Cox (1957) as the simplest type of experimental arrangement in which the treatments are allocated to their units of variation in a completely random manner. This is suited to small-scale experiments (with few dependent factors), where the increase of accuracy of experimental projects in randomized blocks does not yield great advantages due to the loss of degrees of freedom.

Considering the independent parameters of this experiment (theoretical forward speed (Vm) (0.36 and 0.7 m s^{-1}); regulation depth of the work (Pr) (150 and 200 mm) and rotation speed (Rot) (342 and 514 min^{-1}), along with the characteristics of the Bertolini 318 mini-tractor, we have two variations of these parameters, which amount to a total of 8 operational combinations. Each combination will hereinafter be referred to as treatment, and each treatment had two repetitions, making up a total of 16 experimental lines. Each experimental line had 5 data-collection points, making a total of 80 sampling points for all the parameters deemed independent for the dimensional analysis. From now on each combination will be referred to as a treatment (Exxx), being that each treatment had ten repetitions, totaling 80 sampling points of all the parameters (Table 1). From this point onwards, the terminology will be as follows: Theoretical working speed, V1 = 0.36 m s^{-1}, V2 = 0.7 m s^{-1}; Rotation speed of the rotary paraplow, R1 = 342 min^{-1}, R2 = 514 min^{-1}; Regulation of the work depth, Pr1 = 150 mm, Pr2 = 200 mm.

The denomination of the treatment will follow this rule: Exyz, where x represents the theoretical speed; y represents the rotation of the tool and z represents the regulation depth. Considering that the test area was divided into 16 experimental lines, and that each one had 10 m useful length of evaluation, plus 2 m of buffer space and 2 more meters to enter the regime, while each line had five data-collection points spread randomly and staked along the experimental line, we have a totally random experimental project.

According to Albiero, (2006), dimensional analysis has two technical requirements that must always be respected: all the variables must have dimensions; all the variables must be in the same system of measurements. The upshot of the first requirement is the need to make manipulations of parameters that are non-dimensional, so as to transform them into dimensional parameters; while the second leads to a homogenization of all the units into only one system of units.

Dimensional analysis

The calculation methodology used in dimensional analysis was predicted by Murphy (1980) and Taylor (1974), described by Langhaar (1951) and Szucs (1980), and applied by Maciel (1993) and Albiero, (2006) to soil tillage machinery.

In this paper, due to the great variety of parameters, referring to various phenomena, quantifications and standards, it was necessary to adapt these parameters to the same system of units, for the sake of simplifying the treatments and calculations, and in this case the system of units best suited to the study was the GCS system (gramme (g), centimetre (c) and second (s)). Thus, the parameters pertinent to the experiment were converted into generic variables broken down into their basic characteristic dimensions (Table 2).

The first step is to convert the parameters relevant to the experiment on generic variables decomposed only in its dimensions basic features. The second step is to mount the dimensional matrix

Table 2. Table of dimensional conversion of the evaluated parameters.

Name	Parameter symbol	Dimension obtained	CGS dimension	Basic dimension
Soil cohesion	c	kPa	kgf/cm^2	$[M].[L]^{-1}.[T]^{-2}$
Internal attrition angle	ϕ	rad	cm	[L]
Original cone index	CI0	kPa	kgf/cm^2	$[M].[L]^{-1}.[T]^{-2}$
Weighted mean diameter	WMD	mm	cm	[L]
Apparent density	γ	g/cm^3	g/cm^3	$[M]. [L]^{-3}$
Lower width of furrow	LW	cm	cm	[L]
Width of fissures	WF	cm	cm	[L]
Raised area	AR	cm^2	cm^2	[L]
Water dimensional	Du	g	g	[M]

composed of the exponents of the basic dimensions. The third step is to check that the matrix is a sub - dimensional vector space of the phenomenon. This means that this must be three dimensional subspace (M, G, T). For such verification is essential to draw the rank of the matrix. So we chose an appropriate subspace and proved that the phenomenon can be represented by a three-dimensional subspace. In this experiment the determinant of this subspace is equal to -2, so the rank of general subspace.

The fourth step is to assemble the system of homogeneous linear equations, through the lines of the dimensional matrix, which represent the dimensions algebraically independent vector subspace. These equations must be equated to zero, because according to Langhaar (1951), considering a homogeneous linear system, the solution of this system are the dimensionless Pi-terms. The fifth step is to assemble the matrix solution, whereas all the parameters are arranged and represented by three main parameters chosen to describe the phenomenon (γ, WMD, c) .

According to Maciel (1993), the number of Pi-terms is determined by the number of variables minus the dimension of the subspace of the phenomenon, thus bringing the Pi-terms responsible for explaining the phenomenon studied, which are assembled in a matrix solution matrix. The rows of the matrix solution are the exponents of the components of the Pi-terms, also called invariants. The sixth step is to determine the correlation between the Pi-terms to find which has the dimensionless graphs behavior better correlated. This determination is made by the correlation matrix. According to Snedecor and Cochran (1989), the correlation coefficient is closely connected with the bivariate normal distribution. The seventh and final step is considering the Pi-terms that have the highest correlation coefficients dimensionless build graphs for the desired parameters.

The basic dimensions considered were mass [M], given in grammes (g), length [L] given in centimeters (cm) and time [T], given in seconds. All the dimensions of the parameters will be converted into these 3 basic forms, and the dimensions that have components of force will be converted into $[M]*[L]*[T]^{-2}$ due to Newton's second law.

With these parameters the dimensional matrix was set up, which represented a vectorial sub-space of the experiment. Thus, we defined a system of linear and homogeneous equations, from which was defined the solution matrix for the experiment, hence the Pi-terms were obtained according to Upadhyaya et al. (2009). With Pi-terms defined, and with a view to easing interpretation of the data, it was necessary to determine the correlation among them so as to find which dimensionless graphs have the best-correlated behaviours. For choosing the best correlated Pi-terms for constructing dimensionless graphs of the sets of treatments, it was considered the greatest correlation coefficients of each treatment for each pair of Pi-terms after operation of the rotary paraplow, and the considered correlation coefficient was the product of Pearson R^2. It should be pointed out that the correlation coefficient of the product of Pearson is a coefficient that addresses the variances of the correlated values (Table 3).

In order to make an assessment of the structural changes and mechanical properties of soil, every variable considered in dimensional analysis were treated by classical descriptive statistics: mean value, variance, standard deviation, minimum value, maximum value and amplitude. As a normality test of the distributions of the measurements of the parameters in the treatments, the tests of Kurtosis and symmetry will be considered, taking as values for rejection of normality: Kurtosis (k >2 or k < 2); symmetry (g > 2 or g < 2) like affirm Snedecor and Cochran (1989) and Montgomery (2004).

RESULTS AND DISCUSSION

The results obtained support the conclusions concerning the conservational characteristics of the rotary paraplow (Table 4). Particularly from the groups of graphs presented, which determined the optimum conservational configurations as a function of parameters for evaluation of soil tilling machines. In Figures 4, 5, 6 and 7, we have a better overall analysis of the tool, through the clear demonstration found experimentally from the variation in behaviour of the soil as a function of the different operational configurations chosen (theoretical speed, rotation of the tool and regulation depth of the work), enabling a determination of the best combination of these operating parameters for the soil studied, so as to respect the requirements of conservation. To determine the best configurations, it should be noted that all the determinations and choices are restricted only to the texture of the studied soil, in the Oxisol ortose case (Freire, 2006), since all the experimental variables have their trends tied to the physical, chemical and dynamic characteristics of this specific texture due to the extremely high clay content in its constitution. All presented data can be considered to pertain to a normal distribution due to tests of kurtosis and symmetry; therefore, the standard deviation is a good measure of dispersion.

In general, the strip prepared by the rotary paraplow have the following main characteristics: furrow upper width (UW), between 12 and 13 cm with standard deviation (SD) of 0.57 cm; furrow lower width (LW), between 21 and 23 cm with SD 1,36 cm; width of lift ups (WR), between 30 and 28 cm with SD 2.8 cm; width of

Table 3. Specified form of the selected Pi-terms.

Pi-terms	Description
$\Pi_2 = \phi$ / WMD	Its physical meaning behaviour of the internal attrition angle of the soil, which indicates the growth of chiseling tension necessary to generate the fault by chiseling and consequent breakdown of the soil, due to the reduction of stability of the soil also related to the breakdown caused by erosive processes
Π_3 = CI0 / c	Its physical meaning the inversely proportional behaviour of the soil, which defines the chiseling tension on the plane of the fault that subsists after the operation, indicating the de-compacting of the soil as a function of the original cone of the soil.
Π_5 = LW / WMD	The relationship between the lower width of the prepared strip and the weighted mean diameter provides a geometric relationship of the strip, relating it to the level of stability of the soil related to aggregation of the soil.
Π_8 = WR / WMD	Provides a geometrical relationship of the strip, relating it to the level of de-compacting due to a change of density and mobilization of the soil considered as subsequent modification of the stability of the aggregates of the soil, de-structuring it.
Π_{10} = WF / WMD	The relationship between the width of the fissures of the prepared strip and the weighted mean diameter provides a geometric relationship of the strip, relating it to the level of de-compacting and extent of the dynamic effects on the soil considered as a subsequent change to the stability of the aggregates of the soil.
Π_{13} =Du / (γ*(WMD)^3)	The relationship between the quantity of water in the soil, its density and the weighted mean diameter permits considerations of the effects of the quantity of water in the soil in relation to its apparent density and the level of its stability, resulting in a dimensionless figure characteristic of the soil in relation to its physical properties.

Table 4. Average tables of all treatments of the characteristics of prepared furrow and soil properties before and after the operation of rotary paraplow.

Before operation									
Treatment	**Samples**	**Mean**	**Variance**	**Standard deviation**	**Minimum**	**Maximum**	**Amplitude**	**Symmetry**	**Kurtosis**
c (Pa)	80	25556	20604801	4189.42	19195	30947	11752	-0.397	-0.618
ϕ (rad)	80	0.41	0.014	0.10	0.29	0.546	0.25	0.003	-0.966
CI0 (kPa)	80	1715	11619	91	1587	1830	243	-0.38	-0.880
WDM (mm)	80	2.40	0.350	0.52	1.85	2.98	1.13	0.075	-1.423
γ (g/cm^3)	80	1.79	0.065	0.24	1.43	2.16	0.73	0.138	-0.386
After operation									
Treatment	**Samples**	**Mean**	**Variance**	**Standard deviation**	**Minimum**	**Maximum**	**Amplitude**	**Symmetry**	**Kurtosis**
c (Pa)	80	19220	14035279	3331.62	14771	23962	9191	-0.137	-0.800
ϕ (rad)	80	0.96	0.151	0.28	0.632	173.137	0.67	0.003	-1.137
CI0 (kPa)	80	201	2224	43	138	259	120	-0.038	-0.776
WDM (mm)	80	2.06	0.270	0.45	1.60	2.55	0.95	0.080	-1.49
γ (g/cm^3)	80	1.21	0.0287	0.15	0.99	1.46	0.47	0.311	-0.103
HR (cm)	80	4.46	1.78	1.31	2.50	6.50	4.00	0.230	-0.10
RA (cm^2)	80	88	2210	32	49	137	88	0.392	-0.715
U (%)	80	22	15.12	3.62	16.6	28.25	11.37	0.268	-0.202
LW (cm)	80	21.66	2.0	1.36	20.1	23.6	3.5	0.305	-0.665
UW (cm)	80	12.75	0.35	0.57	12	13.6	1.6	0.436	0.858
WF (cm)	80	42.48	13.21	3.23	37.7	48.6	10.8	0.411	0.413
WR (cm)	80	30.45	9.36	2.80	26.6	35.1	8.5	0.318	-0.255

cracks (WF), between 40 and 45 cm with SD 3.23 cm; height of lift ups (RA), between 3 and 9 cm with SD 3 cm; depth between 12 and 20 cm with SD of 1.65 cm.

The average WMD of wet soil aggregates before the operation was from 2.54 and 2 mm with SD 0.52 mm; the apparent density before the operation was between 1.73 and 2.0 g/cm^3 with SD 0.15 g/cm^3; the water content before the operation was around 20%; the original cone index was around 1700 kPa with SD 91 kPa and the soil cohesion before the operation was between 22.8 and 30 kPa with SD 4.1 kPa and the internal friction angle before the operation was between 0.3 and 0.46 radians with SD 0.1 radians.

After the operation, the average WMD of wet soil aggregates was between 2.2 and 2 mm with SD 0.45 mm, the cone index in the center of the furrow was

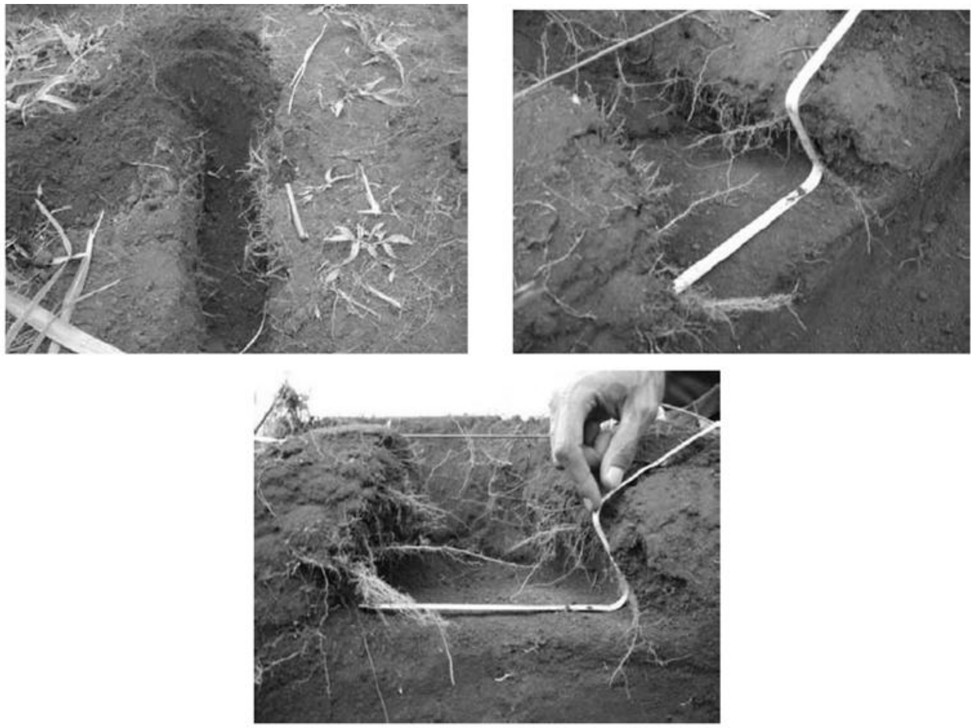


Figure 3. Conformation of the tilled strip prepared for the "Rotary Paraplow".

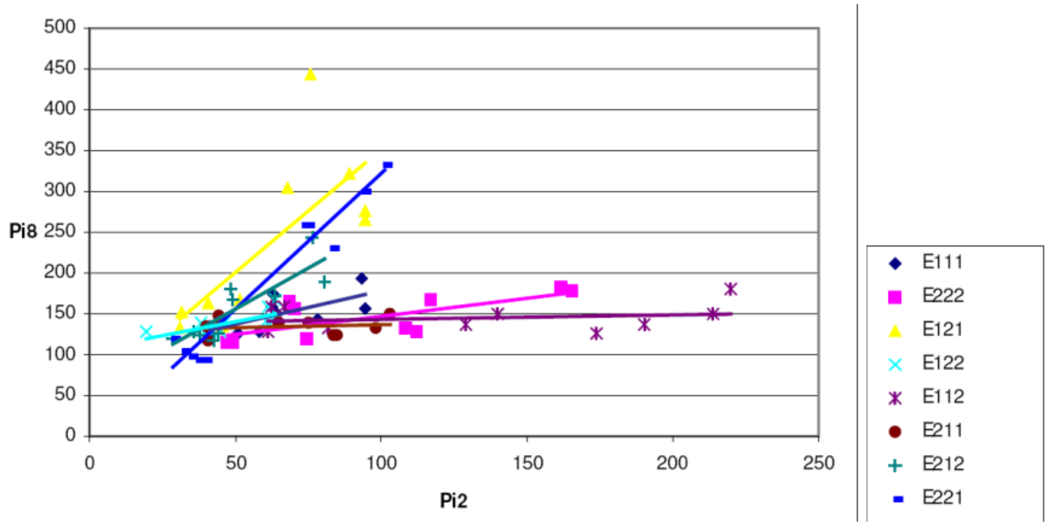
around 2 and 10 kPa with SD 0.43 kPa, the Cone index of the fissures region was around 150 and 250 kPa with SD 34 kPa, the apparent density between 1.3 and 1.0 g/cm^3 with SD 0.15 g/cm^3; the water content after the operation was around 20%, the soil cohesion after the operation was between 13.7 and 23 kPa with SD 3.3 kPa, the internal friction angle after the operation was between 0.6 and 1.8 radians with SD 0.28 radians. According to Upadhyaya et al. (2009) and Mandal et al. (2012), all these parameters are within limits imposed by the literature on the subject in order to consider soil tillage as conservational. The rotary paraplow generated a planting strip with a narrow upper surface and a well-prepared wide lower surface with the formation due to the volumetric subsoil of lateral fissures that improve the infiltration of water (Figure 3). From the data presented in Table 4, one may infer that rotatory paraplow generates a moderate disruption on the soil (decrease of 50% in the soil cohesion and an increase of 50% in the angle of internal friction) without pulverizing it (WDM of 2.0 mm after the operation); therefore, acting in favor of soil conservation. One may observe the decrease of cohesion values, cone index and apparent density of soil, while the internal friction angle increases.

Coulouma et al. (2005) states that different values for soil cohesion lead to different intensities of its fragmentation with a direct influence on its structure, while Maciel (1993) and Bravo et al. (2012) states that in consolidated soils, the cohesion of the soil has greater values, larger values of apparent density, and therefore a behaviour directly proportional to the level of fragmentation of the soil in relation to the resulting reduction of apparent density. Albiero et al. (2011b) states that in consolidated soils the internal friction angle suffers after the soil has been worked by a tool in inverse proportion in relation to the resulting apparent density; thus the greater the internal friction angle the lower the density.

The combined effects of these interdependent parameters generate a great reduction of cone index (8.5 times lower than the original), what in fact is good for soil and plants once it prevents erosion caused by compact and improves soil conditions for water infiltration and root penetration.

The rotary paraplow has these effects mainly due to its volumetric action on subsoil. The rotary paraplow blades, due to its specific geometry, generate a phenomenon of breakdown of the soil in its natural angle of cracks; this crack naturally occurs in the region of soil body which has less resistance, so the disruption of the soil is made in a more efficient manner since it is needed less energy in order to generate larger cracks, in addition to being formed in very specific regions of soil body, known as regions of natural cracks of soil, which depend on the conformation of aggregates, of the amount of organic matter, of the internal variation of textures, and of internal variations in the size of aggregates.

Due to the rotation of the rotary paraplow, vibrations



E111	E222	E121	E122	E112	E211	E212	E221
y = 3,34x - 10,80	y = 0,45x + 102,31	y = 3,03x + 48,23	y = 0,64x + 108,32	y = 0,08x + 129,91	y = -0,21x + 146,37	y = 2,01x + 55,18	y = 3,33x - 10,80
R^2 = 0,9439	R^2 = 0,5087	R^2 = 0,5533	R^2 = 0,4659	R^2 = 0,4439	R^2 = 0,286	R^2 = 0,7367	R^2 = 0,9439

Figure 4. Dimensionless graph π_2 x π_8 containing all treatments.

with lots of frequency components are caused, which correspond to the variation of resistance to soil cut due to “preferred” regions where there are occurrences of cracks; hence, cracks and ripples are produced on the surface of clods of soil. The description of the formation of these cracks is very complex and needs fractal analysis tools (Kataoka et al., 2002; Nussenzveig, 2008). So these cracks occur in oscillations related to the rotative tool and they work in a cylindrical volume around rotary paraplow proved by cracks formed after the use of the tool; these cracks have an expressive width (WF), as shown in Table 4, reaching their size four times more than the furrow upper width (UW).

Thus, when rotary paraplow hits the soil, there is a breakdown in regions naturally established with no disruption “not natural”, in other words, there is a breakdown of soil aggregates by mechanic action; therefore, there is no excessive reduction of WDM of aggregates, becoming possible the reduction of the compact of the soil with no reduction of WDM.

This fact is proved by WDM values, which Lucarelli (1997) and Pinheiro et al. (2004) assert that in conservational systems of soil preparation the WMD value in general falls between 2 to 2.5 mm on surface horizons, which means little turnover of the soil. This is a huge advantage since Osunbitan et al. (2005) asserts that in direct planting systems, the main conservational system, the apparent density is significantly greater in relation to conventional treatments, considering oxisols; thus rotatory paraplow enables the reduction of apparent density and of the soil compaction maintaining the advantages of no-till system.

From the values obtained in Table 4, we have a surface raised in height ranging (HR) between 2.5 and 6.5 cm, which demonstrates movement of the soil without turning over and inversion, besides the effect of elevating the soil due to geometric form of the rotary paraplow. The dimensionless graph Π_2 x Π_8, Figure 4, represents the behaviour of soil breakdown (ϕ/WMD), (π_2) as a function of its movement and de-compacting (RW/WMD), (Π_8). In general, this graph can be considered as an interrelationship between the internal friction angle of the soil (ϕ) and the height of volumetric expansion (RW), as both pi-terms have WMD as denominator. This dimensionless graph demonstrates an intimate link between physical characteristic of soil (ϕ) with its structure (RW), therefore, this graph can also be considered intrinsically physical-structural (Figure 4).

The higher the internal friction angle, the lower the density, and consequently the greater the breakdown of the soil indicated by the width of the raised section, which demonstrates movement of the soil without turning and inversion, besides the effect of raising the soil due to the geometric shape of the rotary paraplow, confirming the soil disturbance below the surface, which according to Rosa (1997) refers to the expansion of the soil in digging operations due to a change in the density of the soil.

The best operational configuration is that in which there is lesser breakdowns (relatively lower values of Π_2) and great mobilization (relatively higher values of Π_8). This focus is seen in Figure 4, where the best behaviours were with treatments E221 and E121, which mobilized the largest areas and concerning relative terms it de-structured less the soil. One may note that both

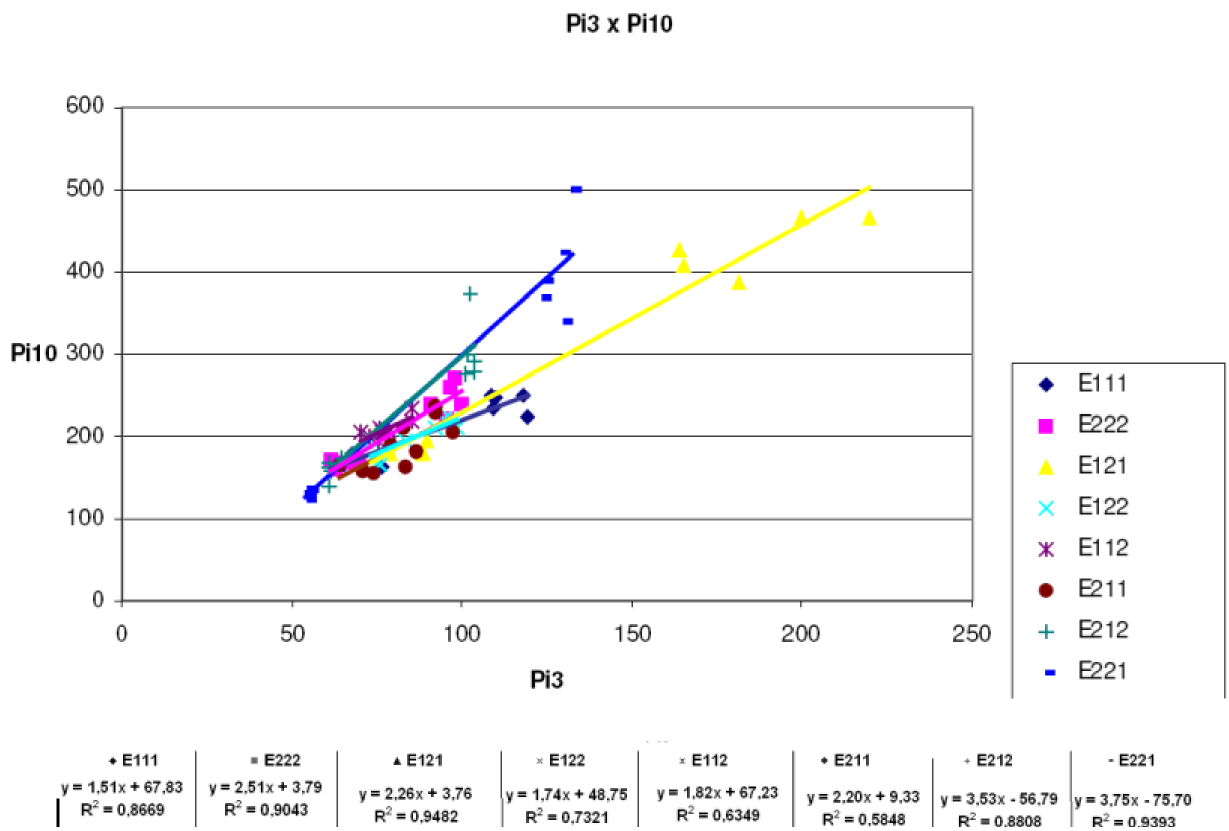


Figure 5. Dimensionless graph π_3 x π_{10} containing all treatments.

treatments have the same combination of operating depth and tool rotation, with only the speed varying, indicating that in terms of breakdown and mobilization of the soil, configuration X21 has excellent characteristics for conservation. An opposed situation is represented by E112 treatment, which presented a high de-structuring demonstrated by high values of internal friction angle, but lower volumetric expansion of the soil, which leads one to understand that the soil volume has not increased because the aggregates were too small, in other words, there was a pulverization of soil aggregates. Another interesting note it that there was a high variation of angular coefficient due to a number of combinations of independent parameters, which indicates that there is a tendency of differentiation of soil de-structuring due to many possible operational configuration.

The dimensionless graph Π_3 x Π_{10} (Figure 5) represents the behaviour of soil de-compacting generated by its de-structuring ((CI0/cohesion)), (Π_3) as a function of the lateral fissures related to the reduction of stability of the aggregates generated in the soil (WF/WMD), (π_{10}). In this dimensionless graphic, it must be considered the information I n Table 3, especially the ones related to WMD and to CI0.

As data is in accordance with a normal distribution, the standard deviation is an acceptable measure of dispersion; thus, when evaluating CI0 standard deviation, a coefficient of variation of 21% is given, so one may consider the value of the cone index as frequent around its average, and the same can be applied to WMD, which has a variation coefficient of 22%; thereby, this graph demonstrates a clear link between the subsoil action of rotary paraplow through the width of fissures (WF) and soil de-structuring due to the reduction of cohesion of the same operation. The turning of the paraplows amplifies such actions due to the consequent periodical vibrations that the soil receives with each rotary cut, since according to Kataoka et al. (2002), the soil is cuted periodically and may have the direction changed due to rotation of the blade. These phenomena cause vibrations which cause sideways chiselling, generating fissures in the soil around the line of action since the rupture of the soil in scarification with a paraplow takes place through lines of fissures that move around the zones where the soil is turned, apparently forming patterns of extensive lateral rupture (Hamilton et al., 2002; Amiotti et al., 2012).

Kataoka et al. (2002) asserts that the forces distributed by the tilling blades generate fissures in the soil that are dependent on the speed of the operation, while the dynamics of these blades and the behaviour of the soil have a highly-complex primary behaviour. The best operational configuration is that in which there is greater

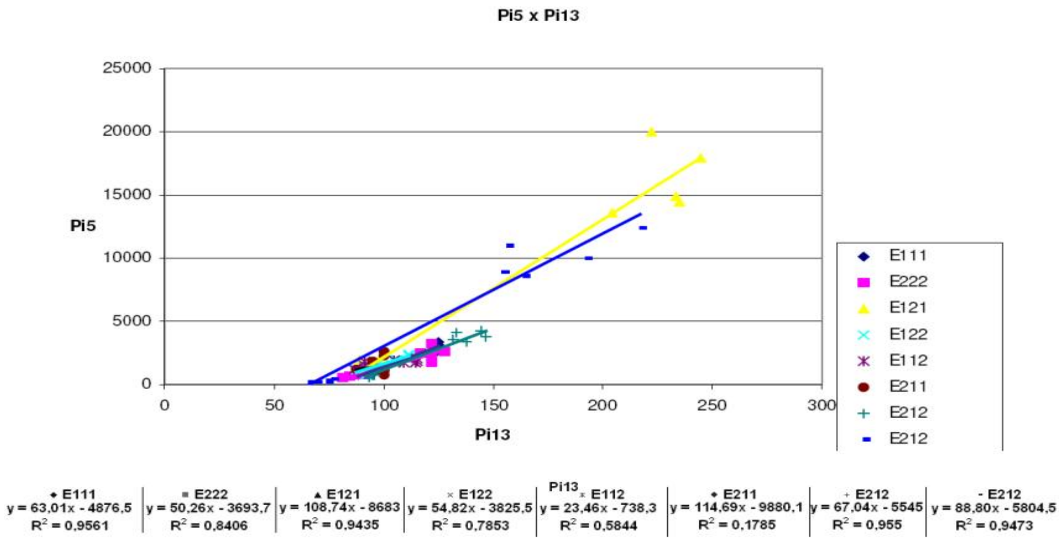


Figure 6. Dimensionless graph π_5 x π_{13} containing all treatments.

de-compacting related to reduction of the coefficient of cohesion (relatively higher values of Π_3) and great lateral fissuration of the soil (relatively higher values of Π_{10}). From this standpoint, one may note in Figure 5 that the best behaviours were from treatments E111, E212, E221 and E121, as they had large bands of de-compacting generated by the de-structuring captured by the variation of cohesion after use of the tool along with high values for width of fissuration of the soil after the operation, due to the action of volumetric scarification produced by the action of the paraplow turning, as the original concept of the paraplow is subsoiling the soil through dynamic actions produced by the design of its geometry, where. The dimensionless graph Π_5 x Π_{13}, Figure 6, represents the behaviour of the lower width of the prepared strip (LW/WMD) (Π_5) as a function of physical and structural properties of the soil (Du / (γ*(WMD)^3);), (Π_{13}).

The immediate effect in the use of a tilling implement is greater or lesser turning-over caused by the active organ, resulting in a change of the size and distribution of lumps, an increase in the volume of porosity with the consequent reduction of apparent density, and change of thermal, chemical and biological behaviour of the soil. The best operational configuration is that in which for a given value of these properties the values for lower width are greater (higher values of Π_5 in relation to the values of Π_{13}). Thus, for the same range of values of physical properties, the treatments with larger lower widths have an action of soil preparation in trapezoidal form without inversion. From this standpoint, Figure 6 reveals that the treatments with the best behaviours were E212 and E121. It is noticed that both treatments with better results in terms of lower width are opposite in all independent treatment, and that all the other combinations have approximately the same variation rate, either in Π_5 or in Π_{13}. The large lower width is related to operational combinations: low speed, high rotation and little depth; and high speed, low rotations and great depth. These operational combination cause a higher volumetric disruptive action in the region of soil body which is closer to the end of rotary paraplow. This volumetric action refers to the action of oscillatory cut of the soil due to the rotation of the tool; and the greatest effect occurs at the end of the tool due to the turning. This oscillations causes a vibration in the soil that increases the scope of the effect of disruption. When this volumetric action occurs with lower speed and little depth, but with high rotation (E121), the conformation of soil body which receives such vibrations (high rotation) have the maximum effect due to the exposure time (low speed, more time to advance) and the minimum soil resistance (little depth, soil more easily mobilised). Concerning the situation in which it is operated the high speed and very depth, but with less rotation (E212), we have similar effects as soil body receives less vibrations (lower rotation), but in less time (higher speed); therefore, it can be considered with higher frequency acting at greater depths (greater soil resistance) generating the same effect. The dimensionless graph Π_8 x Π_{10}, Figure 7, represents the degree of de-structuring and de-compacting of the soil (RW/WMD), (Π_8) as a function of the lateral width of the fissures generated (WF/WMD), (Π_{10}). In general, this graph can be considered as an interrelationship between the high volumetric expansion of the soil (RW) and the widht of fissures (WF), as both pi-terms has a WMD denominator. This dimensionless graph demonstrates the relation between subsoiling generated by rotatory paraplow (WF) and the generated de-structuring (RW).

These complex characteristics of soil movement of generation of superficial cracks/fissures and the

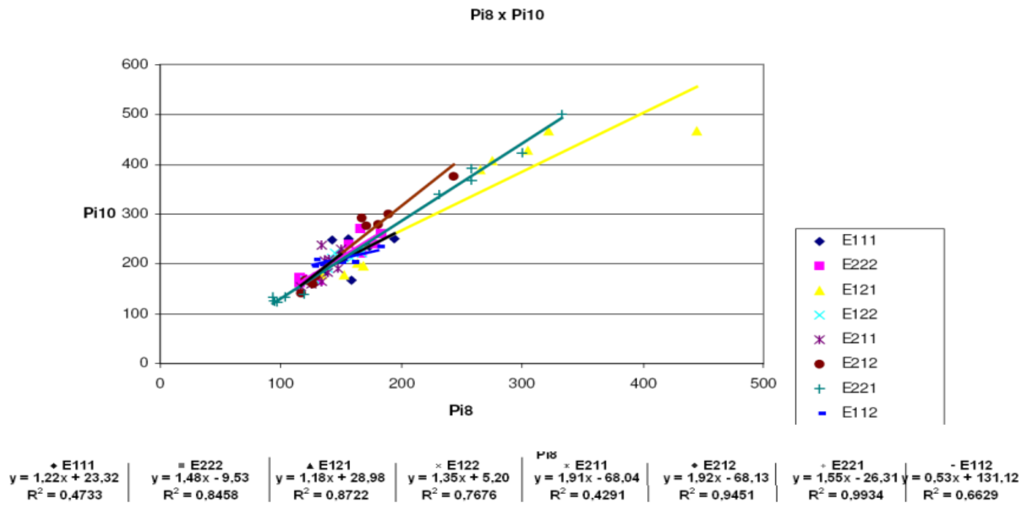


Figure 7. Dimensionless graph π_8 x π_{10} containing all treatments.

volumetric expansion of the soil are interrelated, as can be seen in Figure 7. The angular coefficients of the regression lines present different values for each treatment, which means that the operational combinations influence in subsoiling actions and blistering. The rotary paraplow when generating de-compacting of soil due to it lateral volumetric action (caused by the geometry of blades) has a lift action of the soil due to a vectorial component of cutting force towards to the surface. This force acts especially as an amplifier of cracks and fissures formed by a vibration of volumetric action of tool over soil body. The best operational configuration is that in which great de-compacting has large width of fissures (greater value of Π_8 for large values of Π_{10}).

It is possible to observe that greater widths of fissures occur in treatments E212, E121 and E221, which are also the treatments with greater de-compacting. Another interesting characteristic is that all the treatments have proportional relationships making straight lines with declivities of around 45°, which demonstrates the strict interrelationship between the degree of de-structuring (RW) and de-compacting (WF) of the soil with the width of the fissures.

According Albiero et al. (2011a) the rotary paraplow generated a volumetric subsoiling action generates cracks on the sides of the band, because of their specific geometry the blades of rotary paraplow generate a soil failure according to its natural crack angle, optimizing the energy use, while preserving the natural soil properties.

Conclusion

The rotary paraplow generated a well-prepared subsurface cultivation furrow with a small upper width and a large lower width, characterizing a trapezoidal profile, besides creating lateral cracks as a result from the subsoil volumetric action. The configurations that achieved the best operational and conservational results for each dimensionless graph are listed in decreasing order of success as follows: 1st - E121; 2nd - E221; 3rd - E111; 4th - E212; 5th - E222; 6th E112 and E211; 7th - E122. After operation of the rotary paraplow important changes in structure and in mechanical properties of soil were done. It was generates a moderate disruption on the soil with decrease of 50% in the soil cohesion and an increase of 50% in the angle of internal friction without to decrease the weight diameter mean below of the conservational limit, the cone index decreased 90% and the apparent density decreased 30%, these results show a conservational tillage tool.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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Development of small dams and their impact on livelihoods: Cases from northern Ghana

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Small dams offer a lifeline to rural communities in northern Ghana during the dry season. The paper discusses issues related to water use, socio-economic significance, and sustainability of small dams following substantial State interventions and donor agency investments in the development and management of small dams in Ghana. Through the lenses of political economy narrative, the paper explores the political, economic and social realities that shape the development, operation, and management of small dams. Evidence from sixteen small dams examined, using multiple indicator approach revealed overall satisfactory to highly satisfactory performance indices for small dams. Economic returns from irrigation offer incentives to improve performance but give limited account of performance dynamics of small dams. A holistic view of values and priority attached to multiple uses account for satisfactory performance. Whilst operational limitations of small dams prevail, the paper argues that moving beyond 'technical or engineering fix' and focusing on limitations in national and local institutional arrangements, politics, interests, and rights are crucial for effective planning, management, and enhanced performance of small dams.

Key words: Small dams, development, management, performance, multiple uses, indicators.

INTRODUCTION

Small dams' development has been part of Ghana's rural economy since the post colonial period (late 1950s to mid 1960s). The period saw the construction of approximately 240 earth dams and dug-outs in northern Ghana with the prime objective to provide water for livestock and domestic uses, mitigate recurrent drought impacts, and as well serve as soil and water conservation measure. At the time, the government's policy was geared towards a rapid economic development through massive investment in agricultural production, making the development of large-scale irrigation dams a priority. Such an approach was presumed to be both technically and politically attractive given its massive capability to accelerate social and economic development through the provision of adequate water supply for domestic applications, irrigation, and hydropower generation (Biswas and Tortojada, 2001). However, expectations were hardly met following multi-decades of large scale dam

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Implementation, poor management by government agencies, and challenges associated with operation and maintenance.

The soaring cost of developing large-scale dams coupled with underperformance prompted the government to rethink the idea of dam development in Ghana. This led to a gradual shift towards the development of small dams, informed by the idea that 'small is beautiful' which became a guiding philosophy of many donor intervention policies on dam's development (Swatuk, 2008). Notable among the small dam development projects in Ghana over the past 30 years are the World Bank's Community-Based Rural Development Project (CBRDP), Village Infrastructural Project (VIP), the three IFAD sponsored projects-Land Conservation and Smallholder Rehabilitation Projects (LACOSREP I and II), the German Development Cooperation (GIZ) in the Upper East Region, the Upper West Agricultural Development Project (UWADEP), and the Northern Region Poverty Reduction Programme (NORPREP) for the Northern Region among many others. Currently, there are approximately 1,100 small dams and around 2,500 small- dug-outs with an irrigation potential of between 5,000 and 10,000 ha distributed across the country.

Moving towards the concept of small dams' development came with management and institutional reforms which promoted active participation of local beneficiaries in small dam development. To this end, the Government of Ghana and its development partners invested in the establishment of Water Users' Associations (WUAs) to operate and manage these small dams. The underlying hypothesis was that local communities tend to have greater incentives than external actors to maintain their natural resource base. Organizing local water users in WUAs around small dams has the potential to increase their sense of ownership, leading to improved performance of the system. However, evidence of WUAs performance in operating and managing small dams have had mixed results. While small dams offer significant performance advantages over large-scale dams within irrigation investment projects (Inocencio et al., 2007), debates continue about their performance (Faulkner et al., 2008; Mdemu et al., 2009), impact on the environment and health (Boelee et al., 2009) as well as their long-term sustainability (Andreini et al., 2009). Recent donor-driven investments in northern Ghana have focused on rehabilitating and upgrading existing small dams for mainly irrigation purposes. However, outputs from the small dams irrigated agriculture in terms of yields and farm income have not adequately met expectations. Whilst there is renewed interest to invest more resources into small dam development, there is need to take stock of the performance of these dams vis-à-vis their objectives. For rural areas in northern Ghana, the provision of small dams may be lifeline to socio-economic development by providing great relief during water-scarce periods for multiple uses (domestic water use, livestock use, brick making, and dry season irrigation), fueling socio-economic livelihoods in rural communities (Liebe, 2007).

In evaluating the performance impact of small dams, several researchers have proposed various indicators focusing on internal processes of irrigation system that relate performance to operational objectives such as the area irrigated, crop patterns, and distribution and delivery of water to assess the quality of operational performance (Molden and Gates, 1990). Other indicators emphasize on yield output and economic measures (Behailu et al., 2004; Olubode-Awosola et al., 2006; Faulkner et al., 2008). These indicators have been based on the assumption that a combination of "efficient" technology, markets, and "capable" agencies would result in the best performance (Uysal and Atıs, 2010) often the complex social fabric that influence management and performance of small dams. However, despite the prevalence of technology, market, and agency systems, evidence suggest that in most cases this combination has not resulted in effective irrigation services (Meinzen-Dick et al., 1997). The paper contends that social indicators are also essential and highly linked to the sustainability and performance of irrigation systems.

The paper adopts a holistic approach for the assessment of small dams' performance and their impact in contributing to the socio-economic livelihood of beneficiaries. Using information collected from sixteen small dams in the Upper East and West regions of northern Ghana, we employed eight indicators to characterize the performance of these small dams from the standpoint of efficient use of water, socio-economic output, and sustainability of small dams. In this paper there will be a brief description of the study region and the characteristics of irrigation schemes. This will be followed by an outline of the methodological approach for assessing the performance of irrigation schemes, presentation, discussion of results and conclusion.

MATERIALS AND METHODS

Case study site and characterisation of small dams

The Upper East and West regions are part of the three northern regions of Ghana. Considered as the two most deprived regions in Ghana, majority of the people live in rural areas and their main source of economic livelihood is rainfed agriculture (Ghana Statistical Service (GSS), 2010). Seasonal rainfall pattern in these regions is uni-modal with averages ranging between 800 and 1200 mm. The rainfall season starts in April and ends in October reaching its peak in August, followed by a long dry season from October to April. Seasonal rainfall is highly erratic with high intensity which barely infiltrates the soil (Liebe et al., 2005). Mean temperature ranges from 28 to 30°C. The vegetation is mainly savanna grassland dotted with two important economic trees most commonly shea butter, *Butyrospermum paradoxum*, and *Parkia clappertonian.* Soils in the regions are vulnerable to erosion, have low water retention capacity and low fertility. Millet, sorghum, maize, and groundnuts are the principal crops grown during the wet season. Small dams offer a relief during the dry season as it serves

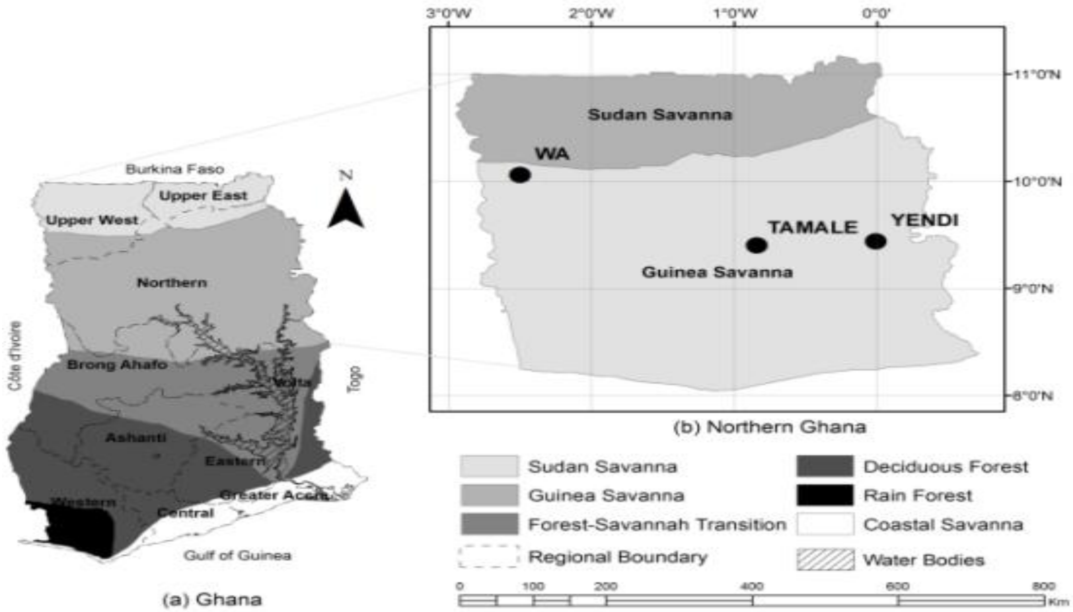

Figure 1. Map of Ghana showing the two regions in northern Ghana and the vegetation type (Source: Dosu, 2011).

Table 1. Principal characteristics of selected small dams in the Upper East (UER) and West (UWR) regions.

Dams	Year	No. of users	Designed irrigable area ha)	Irrigated area (ha)	System type	Water supply	Dam type	Spillway type	Crops grown
Boya Kpal	1945	400	-	-	-	-	Earth	Concrete	-
Zanlerigu	2000	500	9	4	Pipe/wells	Pump	Earth	Concrete	Mixed vegetables
Datuku	2001	1050	10.5	2	Lined canal	Gravity	Earth	Concrete	Mixed vegetables
Nayoko	2000	1200	8	3	Lined canal	Gravity	Earth	Concrete	Mixed vegetables
Kunkwak	2002	620	10.5	1	Lined canal	Gravity	Earth	Concrete	Mixed vegetables
Gumyoko	1960	3000	15	8	Lined canal	Gravity	Earth	Concrete	Mixed vegetables
Dorongo	1963	1000	12	12	Lined canal	Gravity	Earth	Concrete	Tomato
Kamega	1965	3500	10	7.6	Lined canal	Gravity	Earth	Concrete	Onion
Nyimati	2006	1196	10	10	Wells	Motorised pump	Earth	Concrete	Mixed vegetables
Demangye	1998	1600	5	2.7	Wells	Motorised	Earth	Concrete	Tomato
Kaleo	1963	2500	12	3	Pump	Motorised pump	Earth	Concrete	Mixed vegetables
Goli	1998	1500	15	5	Lined canal	Gravity	Earth	Concrete	Mixed vegetables
Babile	1990	7500	8	5.2	Lined canal	Gravity	Earth	Concrete	Mixed vegetables
Tarsaw	2003	2000	20	2	Pump	Motorised pump	Earth	Concrete	Mixed vegetables
Tumu	1963	2000	25	1.5	Pump	Motorised pump	Earth	Concrete	Mixed vegetables
Karni	1944	2245	9	9	Lined canal	Gravity	Earth	Concrete	Mixed vegetables

multiple purpose including domestic, livestock watering, irrigation and many others. Irrigated crops during the dry season around the small dams include tomatoes, leafy vegetables, onions, pepper, shallots and carrots. Most irrigated areas are characterised by mixed vegetable cropping.

Small dams play a crucial role in the production of market vegetables such as onions, pepper, tomatoes, and other leafy vegetables during the dry season. Approximately 482 small dams (with estimated irrigable area of 2210 ha) are concentrated in northern Ghana. The estimated flood area at Full Supply Level (FSL) for small dams ranges from 3 to 14 ha with a storage capacity of up to 1 million cubic meters (MCM). All the dams have earthen embankment with length ranging from 200 to 400 m. As a measure to check erosion, vetiver grasses are grown on the side of the dam walls. Water may be available throughout the season in most of the dams. Majority of the dams are equipped with either lined or earth canal with very few having motorized pumps. Irrigable areas are estimated from 5 to 25 ha. Table 1, presents detailed characteristics of the selected small dams from the Upper East and West regions of northern Ghana.

Data collection and analysis

In understanding the social, economic, political and technical perspectives that influence the development of small dams in the country, the paper adopts a multi-tier approach to data collection. First, databases of small dams from the Ghana Irrigation Development Authority (GIDA) and Ministry of Food and Agriculture (MoFA) were collated and inventoried. Second, the inventory of small dams was validated through field visit to all dam sites and a Rapid Participatory Opportunity/Constraint Appraisal approach (RPOCA). Under the RPOCA approach, Agricultural Extension Agents (AEAs) who oversee the dams in their operational areas were engaged in a participatory working session to verify the dams' condition. At the national level and district, we conducted key informant interviews with policymakers (Ministries of Water Resources, Agriculture, Irrigation and Environment), donors, technical development partners (IFAD, World Bank, GIZ, etc.), and Non-Governmental Organizations who are key stakeholders in the development and implementation of small dams' projects in the regions.

Third, sixteen small dams were selected at random from various districts in Upper East (UER) and West (UWR) regions. Detailed studies of the 16 dams were conducted using field observations and Focus Group Discussions (FGDs) to gain both qualitative and quantitative understanding of small dams' performance and impact on the livelihood of water users. The Upper East and West regions provided suitable study areas to explore in depth and understand the incentives, local or national interests, and institutional arrangements that hinder or encourage the development of small dams. The FGDs comprised the Chief and elders of the community, randomly selected groups from the various water users including; irrigator groups, livestock farmers both in and outside the community, women, fishermen groups, and brick makers. Semi-structured interviews were also conducted targeting individual small dams' users (livestock farmers, irrigators, fishermen, women, etc.). Finally, key informants in the community namely local elected representatives, head of organizations, customary authorities and leaders of WUAs were also interviewed to gain insight into how the various institutional arrangements contribute to small dam's management in improving performance and impact.

Performance index analysis

The paper considers several indicators comprising of physical, social and economic variables in order to capture an overall assessment of small dams' performance. These include: the status of the physical conditions of the dams and their infrastructure such as valves, canals, outlets, pumps, etc.; whether they have broken down before; leakages or in good shape to maintain water flow; the level of operation and maintenance (O&M) of dams which entails proper functioning of the small dams as well as the maintenance culture of water users; equitable access to water and water availability which entail the ability of small dams to provided water for all water users throughout the dry season; the dams' importance to the community showing the extent to which the community or water users value the small dam; the extent to which the WUAs are organized and active to efficiently manage the smooth operation of small dams; the rate of water fee collection; and the level of management of small dams by the WUAs or community. The selection of indicators was done through a literature survey on assessment of performance of small-scale irrigation dams (Vermillion et al., 1999; Turner, 1994), and deliberation on these indicators at the focus group discussion to determine the importance of indicators in defining performance of small dams.

The study adapts the indicator approach which has been employed in the field of climate change to assess the vulnerability of communities or individuals to the impact of climate change and variability (Gbetibouo et al., 2010). The indicator approach employs specific set or combination of indicators (proxy indicators) and measures performance by computing indices, averages or weighted averages for selected indicators. This approach is applicable at any scale (e.g., household, county/district, or national level). Although the indicator approach is subjective in terms of selection of variables and application of indices, we find this approach very suitable as it is able to capture the multi-dimensionality of small dams' performance in a comprehensible form.

Performance indicators are ranked from 1 (Lowest) to 5 (Highest) by water user groups and extension agents from the various irrigation dams. In calculating the overall performance index for each dam, we standardised the values by using a ranking and scoring system to calculate the coefficient of the indicators. The highest performance indicator value is assigned the highest co-efficient value of 1.0 (on a scale from 0.0 to 1.0). The coefficients for the remaining indicators are calculated by dividing each indicator values by the highest indicator value.

The next step is to assign relative importance – weight (0.0-1.0) to the indicators. Three methods of assigning weights to indicators were identified from literature and used namely: (1) statistical methods such as principal component analysis (PCA) or factor analysis (Cutter et al., 2003); (2) arbitrary choice of equal weight (O'Brien et al., 2004); and (3) Expert judgment (Brooks et al., 2005). Statistical method such as the PCA was deemed as the most optimal approach; however, it minimized the contribution of individual indicators which did not move with other individual indicators. The development of weights via expert judgment has proven to be effective but it is often constrained by difficulties in reaching a consensus on the weights among expert panel members (Lowry et al., 1995). Local knowledge and traditional relevance of indicators, mostly unaccounted for in statistical method such as PCA were important towards the determination of vulnerability in the local context. Here, we go beyond just expert judgement by including local knowledge and traditional importance or value in attaching weight to indicators through consultations with the various small dam user groups including irrigators, livestock farmers, fishermen groups, women and WUAs. The performance index of an indicator is calculated by multiplying its weight factors by its coefficient (on a scale of 0.0 to 1.0).

Yield and economic output analysis

Yield data for irrigated crops in the small dam during the 2010/2011 dry season cropping were collected from irrigated farmers. With irrigated area of most small dams being mixed cropped, yield values per ha were standardised by converting yield (kg) to monetary value (in US$) taking into account the exchange rate at that time. The average irrigated plot per farmer ranges from as little as 0.05 to 1.5 depending on the number of farmers and the size of the irrigated area. The net revenue per farmer is estimated by dividing the estimate net revenue per ha by the number of farmers operating in the irrigated area. Economic benefit is considered as one of the prime objectives of small dams' development to provide supplementary income to farmers.

Following the outcome of the various indicators, the paper discusses the results through the lenses of political economy narrative using the actor-oriented approach to explore the political, economic and social realities that shape the development, management and performance of small dams. This actor-oriented approach has firm theoretical foundations based on critiques of prevailing structuralist development ideologies and practices (Apthorpe and Gasper, 1996; Clay and Schaffer, 1984; Long and Long, 1992) and acknowledges the complexity of interactions that occur between actors in the implementation of programmes at both field level (Biggs, 1997; Jackson, 1997) and institutional level

Table 2. Performance indicator indices for small dams in Upper East region.

Indicators	Indicator coefficient								Weight	Indicator performance index							
	Boya Kpal	Zanle-rigu	Dat-uku	Nay-oko	Kunk-wak	Gum-yoko	Doro-ngo	Kam-ega		Boya Kpal	Zanl-erigu	Datu-ku	Nay-oko	Kun-kwak	Gum-yoko	Dor-ongo	Kam-ega
Physical condition	0.40	0.60	1.00	0.40	0.60	0.40	1.00	0.80	0.05	0.02	0.03	0.05	0.02	0.03	0.02	0.05	0.04
O&M	0.40	0.60	0.60	0.40	0.60	0.80	0.80	1.00	0.10	0.04	0.06	0.06	0.04	0.06	0.08	0.08	0.10
Water availability	1.00	1.00	1.00	0.75	0.75	1.00	1.00	1.00	0.20	0.20	0.20	0.20	0.15	0.15	0.20	0.20	0.20
Equitable access	0.80	0.80	0.80	0.80	0.80	0.80	0.80	1.00	0.15	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.15
Importance	0.60	0.80	0.60	0.80	0.80	1.00	1.00	1.00	0.10	0.06	0.08	0.06	0.08	0.08	0.10	0.10	0.10
WUAs	0.20	0.60	0.60	0.20	0.80	0.80	0.80	1.00	0.20	0.04	0.12	0.12	0.04	0.16	0.16	0.16	0.20
Water levy	0.25	0.25	0.25	0.25	0.50	0.25	1.00	1.00	0.05	0.01	0.01	0.01	0.01	0.03	0.01	0.05	0.05
Management	0.20	0.60	0.60	0.40	0.60	0.60	0.80	1.00	0.15	0.03	0.09	0.09	0.06	0.09	0.09	0.12	0.15
Overall performance index										**0.52**	**0.71**	**0.71**	**0.52**	**0.72**	**0.78**	**0.88**	**0.99**

(Grindle, 1997). The actor-oriented approach acknowledges human action and consciousness as the central role in shaping situations. The actor-oriented approach "calls for a detailed ethnographic understanding of everyday life and of the processes by which images, identities and social practices are shared, contested, and negotiated by the various actors involved (Long and Cruz, 2003)". This has strong implications on how we look at the implementation of small dams' development and management.

RESULTS

Performance indicators

Data in Table 2 show that in the Upper East region, majority of small dams were in poor to average physical infrastructural conditions. On how small dams are operated and maintained, most of the small dams were poorly to averagely maintained to facilitate operation, with the exception of three dams that were adequately maintained. On availability of water, equitable access to water and the importance of dams to communities, majority of small dams received favorable scores as reliable source of water needs. In half of the small dams, Water Users' Associations (WUAs) were poorly organised to manage the operations of small dams. On the collection of water levy for small dams' minor maintenance, most of the dams performed poorly in mobilizing financial resources from the water users. Poor to average management practices characterize majority of small dams in this region.

In the Upper West region, data in Table 3 show that two small dams were regarded to be in excellent physical infrastructural conditions while majority of the small dams were in poor to average conditions. On the operation and maintenance, most of the small dams received satisfactory level of maintenance, with the exception of one small dam which was poorly maintained. Majority of the small dams received satisfactory scoring on the availability of water, equitable access and the importance of dams to communities. In more than half of the small dams, WUAs were poorly organized and inactive to manage the operations of small dams and this reflected in the poor water levy collection rate. Majority of the small dams were not adequately managed.

In Tables 2 and 3 we present the indicator performance indices and the overall performance index for each dam. In the Upper East region, six dams recorded highly satisfactory performance indices with Kamega dam emerging as the dam with the highest performance index (0.99) whilst Boya Kpal and Nayoko had the least performance indices.

In the Upper West region, three dams performed very satisfactorily with only two dams recording the highest overall performance indices of 0.97 and 0.94 respectively. The overall performance indices for the remaining dams ranged from average (0.5) to a little about average (0.6).

Economic output from selected small dams

Table 4 provides a summary of economic value of irrigated crops from the selected small dams. The net revenue of crop yield per hectare per season from irrigated agriculture ranged from US$300 to US$1400 for the Upper East and US$550 to US$1700 for the Upper West region. These wide ranging economic values per hectare appeared to be considerably decent for irrigated agriculture given that the daily minimum wage for the country

Table 3. Performance indicator indices for small dams in Upper West region.

Indicators	Indicator coefficient								Weight	Indicator performance index							
	Nyi-mati	Dem-angye	Kal-eo	Goli	Bab-ile	Tar-saw	Tumu	Karni		Nyi-mati	Dem-angye	Kaleo	Goli	Bab-ile	Tar-saw	Tumu	Karni
Physical condition	1.00	0.40	0.60	0.80	0.80	0.60	0.60	1.00	0.10	0.10	0.04	0.06	0.08	0.08	0.06	0.06	0.10
O&M	1.00	0.60	0.60	0.60	0.80	0.60	0.80	0.80	0.15	0.15	0.09	0.09	0.09	0.12	0.09	0.12	0.12
Water availability	1.00	0.80	0.80	0.60	0.80	0.80	0.80	0.80	0.15	0.15	0.12	0.12	0.09	0.12	0.12	0.12	0.12
Equitable access	1.00	0.60	0.60	0.80	0.80	0.60	0.40	1.00	0.10	0.10	0.06	0.06	0.08	0.08	0.06	0.04	0.10
Importance	1.00	0.60	0.60	0.60	1.00	0.80	0.80	1.00	0.20	0.20	0.12	0.12	0.12	0.20	0.16	0.16	0.20
WUAs	0.80	0.20	0.20	0.20	0.80	0.60	0.40	1.00	0.15	0.12	0.03	0.03	0.03	0.12	0.09	0.06	0.15
Water levy	1.00	0.25	0.25	0.25	0.75	0.25	0.25	1.00	0.05	0.05	0.01	0.01	0.01	0.04	0.01	0.01	0.05
Management	1.00	0.40	0.40	0.60	0.80	0.60	0.60	1.00	0.10	0.10	0.04	0.04	0.06	0.08	0.06	0.06	0.10
Overall performance index										**0.97**	**0.51**	**0.53**	**0.56**	**0.84**	**0.65**	**0.63**	**0.94**

in 2010 was $2 according to the Ministry of Finance and Economic Planning. However, the net revenue of irrigated crop yield per farmer ranged from US$15 and US$90 in the Upper East and US$50 to US$750 in the Upper West region. These revenues for irrigated crop yield excluded labor cost because labor was usually provided by family members.

DISCUSSION

Impact of physical condition on small dams' performance

In all the dams surveyed, it was a common observation that the physical condition of dams and their infrastructure to a greater extent reflect their level of maintenance and management. The physical condition of low performing dams are often charaterised by eroded and seeping dam walls, faulty and broken valves and canals, and spillway failure which in many cases could be attributed to poor maintenance culture of beneficiary communities. These problems on several occasions contributed to the drying up of small dams. In some cases, poor infrastructural conditions, by default, emerged from poor planning and implementation of small dams' project by contractors with political clouts but limited technical knowhow related to small dams' development.

The development approach of these small dams mimicked the top-down approach of large-scale dams' projects which in part accounted for their underperformance (Nkhoma, 2011). Adams (1992) argued that small dams "have been a little more scaled down version of large projects with similar high technology irrigation systems developed through top-down planning processes dominated by government bureaucracy" (For details on the politics of small dams' development, see Venot et al., 2011). In the course of the paper, we will see how this bureaucratic approach has negatively impacted on the performance of small dams. The need to factor in local and historical context in the process of developing and implementing small dams cannot be over-emphasized if satisfactory performance of small dams is anticipated.

Whilst physical constraints may hinder efficient functioning of small dams particularly for irrigation, they do not necessarily influence yield outputs and water provision for multiple uses. In certain cases, small dams have the capacity to store water throughout the dry season irrespective of physical conditions, making water available for various uses. For example, livestock users would describe small dams as performing satisfactorily provided they are able to supply water for livestock through the dry season. Again, in some small dams where irrigation facilities were uncompleted or even absent, farmers cultivated crops under irrigation by digging wells and constructing earth canals to channel irrigated water to their farm plots.

Social and institutional realities of small dams development and performance

Equitable access to water is shaped by a preconceived notion that water is a free commodity" or "gift" and each member of the communities has the right of access. This is not to

Table 4. Economic outputs of small dams in the Upper East and West region.

Small Dams	Irrigated area	Irrigated area per farmer	Number of farmers/ha	Net revenue US$/ha	Net revenue /farmer US$
Upper East					
Boya Kpalsiako	-	-	-	-	-
Zanlerigu	1.5	0.1	17.0	838.7	49.3
Datuku	2.0	0.1	10.0	603.3	60.3
Nayoko	8.0	0.1	17.0	358.7	21.5
Kunkwak	3.0	0.1	17.0	682.0	40.9
Gumyoko	11.0	0.1	20.0	370.0	18.5
Dorongo	12.0	0.1	10.0	898.7	89.9
Kamega	7.6	0.1	20.0	1376.0	68.8
Upper West					
Nyimati	10.0	0.1	11.0	562.0	50.6
Demangye-Ko	2.7	0.1	10.0	-	-
Kaleo	1.5	0.1	10.0	826.7	82.7
Goli	5.0	0.3	4.0	1669.3	417.3
Babile/Tanchara	5.2	0.1	10.0	570.0	57.0
Tarsaw	2.0	0.5	2.0	1462.7	731.3
Tumu	1.5	0.3	4.0	938.7	234.7
Karni	9.0	0.3	4.0	1252.7	313.2

say that water is not contested resources in small dams. Keen water contestation may arise based on the different priorities of the multiple actors involved, for example between irrigators and livestock farmers over access to water in some dams. For example, in one of the dams, extension of irrigated area with the aid of motor pumps culminated in high water contestation which threatened to disrupt the planned irrigation scheduling in the dam. Access is not only a function of availability of water infrastructure but also a function of local institutions and processes that ensure access to those assets (Cotula, 2006).

Conflicts rarely occur concerning the water uses in small dams but conflicts may occur between implementing agencies and beneficiary communities. Whilst the model for small dams' development has been lauded a participatory approach, local communities have questioned such participatory tenets by criticizing development agencies of prioritizing irrigation at the expense of other important uses such as livestock watering, fishing, molding blocks, and construction. The implication is that, local beneficiaries tend to be delusional about small dams ownership and management.

In rural part of northern Ghana, state policies and legislations on water resources tend to have very little impact, rather local norms or traditional rules tend to shape decision making in communities around resources including the right of access, use, and management of small dams (Laube, 2007). For instance, in most communities, it is morally unacceptable to deny people access to drinking water, and denial might cause severe conflicts (Laube, 2007). This is not to say that practical exclusion from access does not occur. The right of access to water in small dams may be based on bodies of norm such as traditional rules and customary laws. Exclusion may occur not on legal arrangement basis, but on local power hegemonies viewed by the population as uneven or even illicit (Eguavoen and Spalthoff, 2008). However, these rules or norms may evolve over time as a result of diverse factors like cultural interactions, social-economic changes, migration, and political changes.

Characterizing low and average performing small dams at the local level was the low level of organization and activeness of WUAs in their operation and management of small dams. While WUAs are regarded as managers and decision makers around small dams, principally to undertake minor maintenance and daily management activities, there exist several local institutions that are connected to each other and to other levels of decision making, contributing to different and complementary roles in the governance of small dams (Eguavoen, 2007). The traditional authority led by the chiefs still plays an important role over small dams perceived as a common property, often held in trusteeship by chiefs or spiritual leaders. Although, chiefs and elders play a limited role in the day to day decision making on small dams, they function to activate and enforce social norms of behavior through established patterns of authority and leadership in events that require major decisions concerning the small dams (Gyasi et al., 2006). They are known to settle disputes, resolve conflicts and maintain social cohesion.

They also enforce local rules governing water resources by threatening perpetrators with spiritual or social sanctions, sometimes in co-operation with local administrative or political bodies (Laube, 2008). They hold the prerogative to allocate land for irrigation, sanction communal labor for small dams' maintenance and empower WUAs by enforcing rules and regulations on the use of small dams. However, WUAs are viewed as an "external package" that do not account for pre-existing socio-environmental conditions and cultural norms that influence decision making, limiting their scope to contribute to sustainable management.

Another indicator linked to WUAs is the degree to which water use levies are mobilized by WUAs. Majority of small dams are charaterised by very poor rate of water use levy mobilization which likely reflected in the level of activeness and organisation of WUAs. Funding for small dam development has always come from international development donors or government coffers without the financial input from WUAs or beneficiary communities. With very limited financial capacity or no financial stake in small dams' development, WUAs are expected to mobilize funds through the collection of water use levies ranging from US$0.5 to US$2 per person per season. Water levies serve as seed money for minor maintenance and to access credit and loans for inputs.

Although, monies collected may be insignificant for even minor repairs, payment tends to incentivize water users commitment, stimulating a sense of participation in operation and management of small dams. Considering that uses such as livestock water, domestic uses, etc. are non-commercial, water use levies are charged to mainly irrigators which in part account for the unwillingness to pay. Whilst some level of success could be credited to the effective organization of WUAs in some small dams, majority of WUAs according to water users have performed below expectation as a result of weak financial position of WUAs. The paper argues that whilst the presence of social engineered approaches such as the WUAs are relevant for sustainable management of common resources, they do not necessarily translate into high performance, in this case, of small dams.

To be recognized as effective WUAs requires functional structure that organizes themselves through regular activities in small dams and also has the ability to mobilize internal funds through water levies. The ability of WUAs to organize for effective water management may sometimes rest on socio-cultural incentives and on their ability to link effectively with other pre-existing traditional institutional arrangements. This is backed by the fact that social capital generated conditions such as norms, religion and culture seem to have a stronger organization for natural resources management than the social capital created by "institution fix" such as the WUA (Meizen-Dick, 2008). In contrast, Khanal (2003) argues that by recognizing that WUAs are partisan, political and heterogeneous bodies, it will be possible to understand their dynamics and avoid dysfunction.

Economic impact of small dams

Economic productivity provides a diagnostic tool for identifying the monetary value of water use for irrigation in small dams. Among the multiple uses of small dams, irrigation is singled out as the most economically viable strategy which stimulated the construction or rehabilitation of several small dams. With massive demand for vegetables during the dry season, farmers have the opportunity to maximize income from irrigated agriculture, which has the potential to positively impact livelihoods (Faulkner et al., 2008). High economic output from irrigation provides mixed interpretations with regards to their influence on the performance of small dams. In some cases, substantial economic output may reflect positively on the overall performance of small dams. Economic output driven by readily accessible markets for irrigated crops offers incentive for proper management and sustainability of small dams. In other instances, low to average performing small dams are able to produce high economic output irrespective of the constraints. In as much as net revenue per hectare may be significant, crucial to farmers is the individual income. Whilst economic returns from irrigation may partially influence the performance of small dams, it remains an essential component for small dams' sustainability and rural economic livelihood.

Focusing on the so-called "economically viable irrigation" as the principal yardstick for small dams' performance might be counterproductive where reproductive concerns –illustrated by livestock activities, fisheries, breweries, domestic water needs- may predominate. Small dams have social meanings and local populations value them for the multiple uses, which tend to translate into their perception about small dams performance (Venot et al., 2012). In most cases, local people were highly satisfied suggesting that small dam's performance depends on the interest and priority use of beneficiaries. For instance, multiple users of small dams for livestock, fishing, breweries, domestic uses, and brick making gave high ranking performance of small dams. Performance is centered on small dams' capacity to make water available for multiple uses throughout the dry season irrespective of their physical conditions. Priorities of water use for different activities exist in the different regions. For instance, in Upper West region, the initial purpose for small dams' establishment was for livestock watering. In cases of water scarcity, livestock are given the priority over domestic use and irrigation indicating the high premium placed on livestock. Livestock is considered as guaranteed or secured capital and social assets or investment which can readily be turned into fiscal note to cater for household needs during emergencies (e.g. hospital bills, school fees, etc.).

Political realities of small dams' development

The rationale for small dams' development like many development projects originates from a combination of technical, social-economic and political reasons as pointed out by Floch and Molle (2009) for irrigation development. It is widely viewed as a development project sanctioned by international development partners and donors and guided by imported policies or norms whose underlying assumptions contrast with the realities of the areas they are meant to stimulate development (Landell-Mills et al., 2007). Such underlying interplay of politics, power and interest has had serious ramifications on the outcome of such development projects (Tidemand, 2010; Nkhoma, 2011). Small dams are, however, perceived as viable intervention for addressing multiple needs such as recurrent drought, livestock watering, block manufacturing and irrigation with the ultimate aim of increasing food security (Ghana Poverty Reduction Strategy, 2003).

The development of these small dams in Ghana has been undertaken by different implementing agencies through a series of projects at different periods with little or no coordination (Andreini et al., 2005). The lack of proper coordination of different actors in the provision of small dams has resulted in duplication of several rehabilitated small dams. Once these small dams are developed, management is entrusted to WUAs which are established by the small dams' development projects with very little input and knowledge from beneficiary communities. This approach is government's way of shedding operational and maintenance responsibilities to local beneficiaries. With the transfer of responsibilities seldom included in the devolution of power, WUAs were seen as operating in an apolitical institutional vacuum and hardly acknowledged the multiple claims that small dam projects induced.

In principle, WUAs are deemed as bottom-up, user-centered, and participatory, yet they still exhibit the characteristics of a top-down approach to designing and implementing policy and institutional reforms, which Kloezen (2002) refers to as "institutional engineering". Donors and governments entered rural communities, constructed or rehabilitated small dams and imposed specific configuration (e.g.) WUAs) deemed at triggering collective action for effective and sustainable management of small dams. WUAs exemplified collective institutional arrangements served as conduits for reform (Khanal, 2003; Meinzen-Dick et al., 2002; Meizen-Dick, 2008). But, as highlighted by Skjølsvold (2008), water users are seldom involved in the process or are they explained what the objectives are. For some water users, WUAs have been perceived as a platform instigated by politicians at high places to canvas for political vote to secure seat district, regional or even national assembly.

The paper argues that the relatively mixed performance of WUAs can be attributed to the implementation approach that was adopted for their establishment during past development projects, specifically, the lack of attention given to the local social fabric and the multiple actors and livelihood strategies that are organized around small dams. We further argue that the approach is flawed with several deficiencies notably in the way institutional arrangements are shaped and "imposed" by implementing agencies, regardless of the local dynamics of management of natural resources.

One important aspect that remained subtle in the result is the low patronage to irrigated agriculture in many small dams. Although, irrigated agriculture offers economic incentives for rural livelihoods, the increasing pace of many rural households' engagement in broader economy, in particular the impact of urban migration tends to undermine the objective of establishing small dams to improved economic livelihood through irrigation. Rural people especially the productive age group between 15 to 30 years find it more lucrative to migrate to the urban centers to engage in menial jobs as a means of generating income. Upon returning the villages, migrants are able to influence other members of the community about the positive prospects of migration by showing assets acquired from the journey. This to a large extent has reduced labor for both irrigated and rainfed agriculture as well as other socio-economic activities in several small dam beneficiary communities. However, the detailed discussion on migration which account for a substantial part of rural household income is beyond the scope of this paper.

Conclusion

Small dams offer a reliable source of water in an unreliable semi-arid region of Ghana. The paper examines some physical, social and economic indicators that account for small dams' performance. The paper reveals rather intricate results in the performance of small dams when we consider diverse views on uses and values attached to small dams. Performance with regards to each indicator varied considerably in most dams. However, very consistent among high ranking indicators were the availability of water, equitable access, and the importance of small dams in the community. Economic returns from small dams' irrigation reinforce the notion of irrigation as most viable source of rural economic livelihood among other uses. However, in spite of its economic incentives, perceived patronage of irrigation in most dams is unfavorably low possibly due to small dam irrigation as a 'new venture', and a shift by many rural households into broader economy. Although economic returns from irrigation may partially influence the performance of small dams, it remains an important driving tool for small dams' sustainability and rural economic livelihood. It is worth noting that, a skewed focus on a more "productive" irrigation as the principal measure of small dams' performance might be counterproductive where reproductive concerns – illustrated by livestock activities, fisheries, breweries, domestic water needs – may predominate.

Overall, performance of small dams can be said to be a subject of holistically viewing values and priorities in multiple uses offered by small dams to beneficiaries. Small dams are historically and socially constructed through interests of different actors in the local settings. In ensuring sustainability and meeting the demand of contributing food security, economic development, and income diversification, there is need to move beyond small dams as 'technical or engineering fix' by focusing on both national and local institutional and organizational processes that account for the planning, implementation, and management of small dam's development and use.

The development and management of small dams can also be viewed as a political process which engages multiple stakeholders that have conflicting and competing interests and incentives. The use of small dams is rarely contested and their management are shaped by interests, interactions, and priorities of different stakeholders. Given the important contribution of small dams to the development of rural economy and organization of rural society, the paper conclude that taking a holistic approach toward understanding the interaction among stakeholders and local dynamics within broader context of political economy is essential for the successful performance of small dams.

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Conflict of Interest

The findings and conclusions contained within are those of the authors, and do not reflect positions or policies of the Bill and Melinda Gates Foundation.

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Variation of soil properties and phosphorous fractions in three cropping systems of lower indo-Gangetic alluvial plain

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The variation of soil properties and phosphorous fractions in three different cropping systems were investigated in Chinchura-Mogra and Polba-Dadpur block of Hugli District, West Bengal representing lower Indo-Gangetic alluvial plain. One perennial cropping system (mango and banana plantation) and two annual cropping systems (Paddy-paddy and paddy-potato) were selected for this study. Sampling points were selected based on established soil map of the area. Soils of each cropping systems were characterized and the samples were collected for laboratory analysis. Analysis of variance was used to establish significant differences within the cropping system and pedons. Significantly lower clay (27.1%) and organic carbon (0.33%) was recorded in paddy-potato cropping system whereas paddy-paddy cropping system recorded significantly higher clay (53.6%), soil reaction (7.14) and cation exchange capacity (17.85 c mol (p+) kg^{-1}). High available water content (12.11%) was recorded in the plantation system. The results from phosphorous fractionation studies shows that soils of plantation system recorded high Olsen-P (3.57 to 10.91 mg kg^{-1}) and calcium-P (49.20 to 73.56 mg kg^{-1}) whereas paddy-paddy cropping system having high iron-P (10.46 to 27.83 mg kg^{-1}). The epipedons compared to the endopedons of the soils had significantly higher sand, organic matter, available water capacity, phosphorous fractions and lower clay content. The results showed that most of the soil properties were to a greater extent influenced by changes in cropping systems.

Key words: Cropping systems, epipedons, endopedons, soil properties, phosphorous fractions.

INTRODUCTION

The lower Indo-Gangetic Plain (LIGP) of India is primarily a rice based cropping system which has played a key role in realizing the food grain production level needed to sustain a burgeoning population. During 1990's, cropping system was diversified with the inclusion of short duration potato and mustard resulting in higher production per unit area per unit time. The paddy-paddy cropping system is a major cropping system in LIGP which occupies an area of 0.94 M ha. The paddy-potato (including paddy-potato-vegetables and paddy-potato-summer paddy) cropping system is a second dominant cropping system in the LIGP, covering an area of 0.58 M ha (Yadav and Subba Rao, 2001). Perennial cropping systems (Mango and banana plantation) is mainly practiced in levee portion of

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Hugli and other rivers. The other cropping systems like paddy-wheat, paddy-pulses are occupied smaller area in LIGP. Continuous cropping system, intensive cultivation with high water-demanding crops has led to a decrease in groundwater levels, serious water logging and secondary salinisation which ultimately resulted to declining input factor productivity in many parts of LIGP (Ladha et al., 2003; Biswas et al., 2006; Saikh et al., 1998). Different studies have examined variation of cropping systems on soil properties in different parts of the globe (Rachman et al., 2003; Al-Kaisi et al., 2005; Mazarura and Chisango, 2012; Hubbard et al., 2013; Gathala et al., 2013). Long-term soil fertility studies have shown reduction in soil organic matter content due to continuous cropping systems (Saha et al., 2000; Varvel and Wilhelm, 2010). Like other soil properties, the forms and dynamics of soil phosphorous are also greatly affected by land use changes/cropping systems which often involve changes in vegetative cover, and biomass production and agricultural management practice (Solomon et al., 2002; Dossa et al., 2001). Majority of works in Indo-Gangetic alluvial plain has focused to assess cropping systems in terms of soil fertility and nutrient balances (Manoj Kumar et al., 2009; Biswas et al., 2006). Variation of cropping systems on soil properties and phosphorous fractions has not been conducted for dominant cropping systems of LIGP region in India, and this study will provide useful information for establishing sustainability and proper land management practices for cultivations in this region. In this context, the study was carried out to assess the variation of cropping systems on soil properties and phosphorous fractions in lower Indo-Gangetic alluvial plain.

MATERIALS AND METHODS

Study area

This study was carried out in Chinchura-Mogra and Polba-Dadpur block of Hugli District, West Bengal representing lower Indo-Gangetic alluvial plain (Figure 1). Humid subtropical climate prevails in the area with long term mean annual rainfall of 1600 mm. The lowest rainfall of 1129 mm was received in 2003 and the highest amount of 1648 mm during 1999. The mean annual air temperature is 26°C. The difference between the mean summer and mean winter soil temperature is more than 5°C. The soil temperature regime is hyperthermic. The study area belongs to Agro Ecological Zone 15.1 described as the Bengal Basin, hot moist sub humid agro ecological sub region with deep loamy to clayey alluvium derived soils, medium to high available water capacity and length of growing period of 210 to 240 days. The dominant three cropping systems practiced in this region (one perennial cropping system (Mango and Banana plantation) and two annual cropping systems (paddy-paddy and paddy-potato) were selected for this study.

Field studies

Soil map of west Bengal was used as a base map for selection of different sites for sampling (NBSS and LUP, 1992). Sampling points are selected from single mapping unit which have dominant soils of very deep, moderately well drained, coarse loamy soils on nearly level to very gently sloping uplands. Three sites were selected (Figure 2) in each cropping system, profiles were dug and soils were morphologically described (Soil Survey Staff, 2003). Soil samples were collected from each genetic horizon for laboratory analysis. Soil samples were air-dried, crushed and passed through 2-mm sieve, and physical and chemical characteristics were determined.

Laboratory study

Particle size distribution was determined by International Pipette Method (Day, 1965). Soil pH, electrical conductivity (EC) and (Cation Exchange Capacity) CEC were determined using the standard procedures (Page et al., 1982). Soil organic carbon was determined by the wet oxidation method of Walkey and Black (1934). Available Water Capacity (AWC) was calculated as the water retained between suction 0.03 and 1.5 Mpa described by Klute (1986). Different inorganic phosphorous fractions were analysed according to Petersen and Corey (1966). Available phosphorous (Olsen-P) was analysed by using 0.5 M $NaHCO_3$. 1 N NH_4Cl was used to extract easily soluble and loosely bound Phosphorous (Saloid bound P), Aluminium phosphate and iron phosphate extracted by using 0.5 N NH_4F and 0.1 N NaOH respectively. Calcium phosphate was extracted by using 0.5 N H_2SO_4.

Statistical analysis

Analysis of variance (ANOVA) was conducted using SAS (SAS Institute Inc., North Carolina, USA). Differences between three cropping systems and pedons were compared by the least significant difference (*LSD*). Differences between the means were considered to be statistically significant at $P < 0.05$.

RESULTS AND DISCUSSION

Soil morphological characteristics

Morphological properties of studied soils are shown in Table 1 indicating well drained, yellowish brown to brown, moderate medium, sub angular blocky structure silt loam to silty clay loam in surface soils identified in plantation system. The endopedon of these soils are, brown to dark brown, moderate medium to moderate fine sub angular blocky structured silt loam to silty clay in texture with violent to strong effervescence with dil. HCl at various pedal depths. The soils of paddy-potato cropping systems have well drained to moderately well drained, light yellowish brown to brown, moderate medium, sub angular block structured silt loam to sandy loam surface soils with brown to dark grayish brown, moderate medium to weak fine sub angular blocky structured loam to silt loam sub surface soils whereas paddy-paddy cropping system have somewhat poorly drained to poorly drained, dark brown to very dark gray brown, silty clay to silty clay loam surface soils with coarse strong to moderate medium, sub angular blocky structured silty clay to clayey subsurface soils. The soil colours of endopedons of paddy-paddy cropping system indicate that that they are more reduced condition due to lack of oxygen throughout

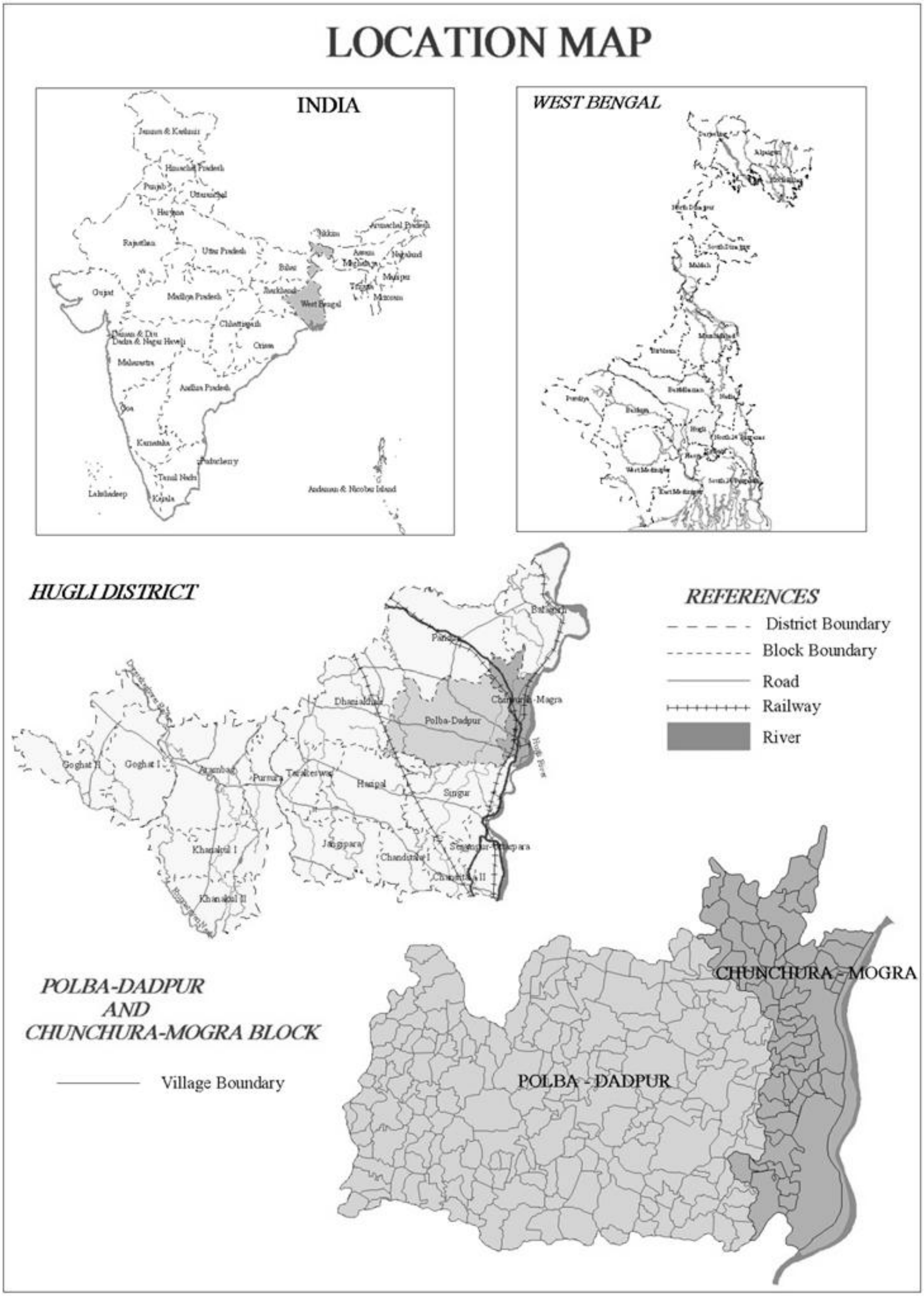

Figure 1. Study area.

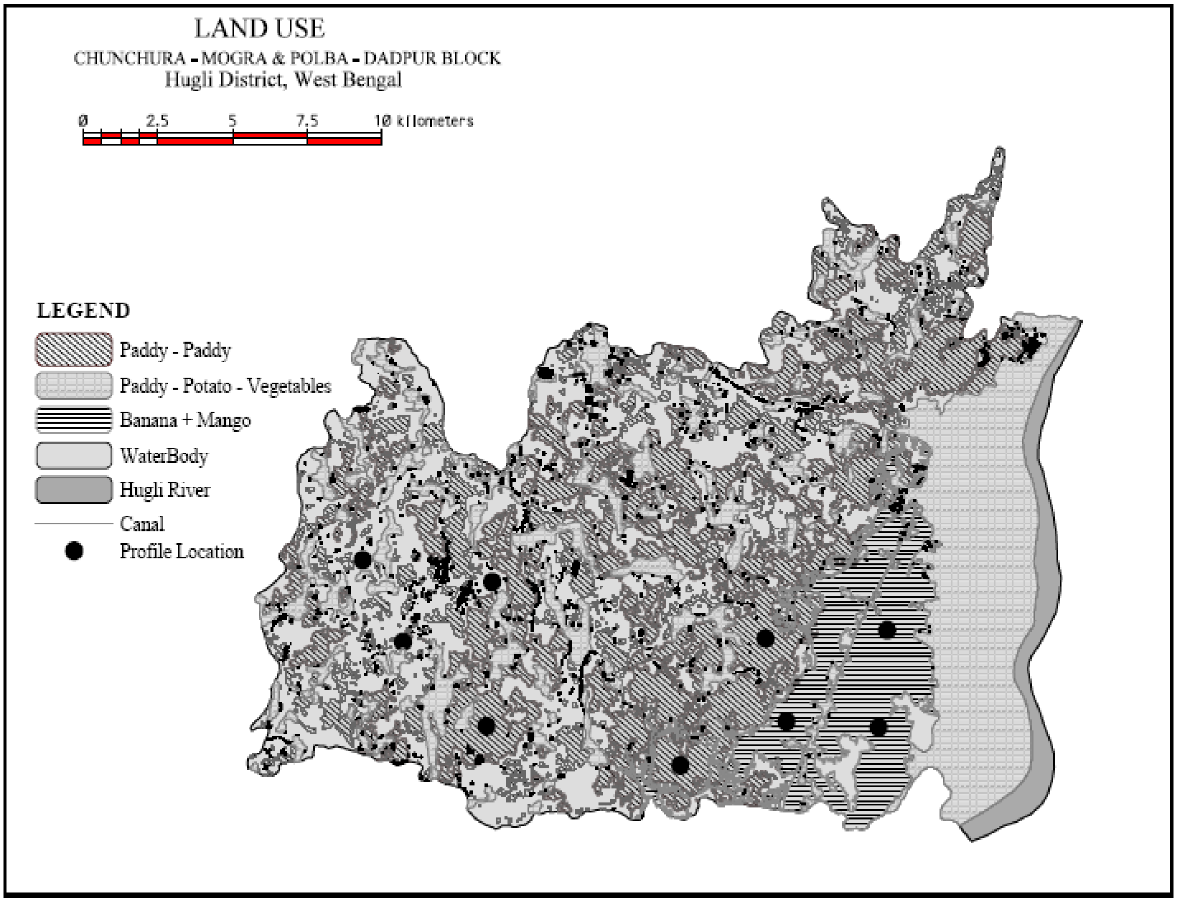

Figure 2. Sampling points.

Table 1. Selected soil morphological features associated with different cropping systems in Lower indo Gangetic alluvial plain.

Cropping system	Horizon	Depth (cm)	Colour (moist)	Texture	Structure	Consistency	Mottles	Reaction with HCl	Drainage
Plantation	A	15	10YR 5/4	sil	m2sbk	fr.ss.po	-	-	WD
	Bw1	23	10YR 3/2	sicl	m2sbk	fr.ss.sp	f1f	es	
	Bw2	47	10YR 3/3	sicl	m1sbk	fr.ss.sp	-	es	
	C1	55	10YR 3/3	sic	massive	fi.s.p	f1f	ev	
Paddy-potato	Ap	25	10YR 5/3	sil	m2sbk	fr.ss.sp	f1p	-	MWD
	C1	54	10YR 4/3	sil	m2sbk	fr.ss.po	m2p	-	
	C2	28	10YR 4/3	sil	f1sbk	fr.ss.sp	m2p	-	
	C3	36	10YR 3/4	sil	f2sbk	fr.ss.po	m2p	-	
Paddy-paddy	Ap	23	10YR 3/2	sic	massive	fi.ss.p	f1p	-	PD
	Bw1	28	10YR 3/1	c	c3sbk	fi.s.p	-	-	
	Bw2	44	10YR 3/1	c	c3sbk	fi.s.p	m2p	-	
	Bw3	40	10YR 3/2	c	c3sbk	fi.s.p	m2p	-	

Sil- silt loam, sicl- silty clay loam, sic- silty clay, c- clay; m2sbk- moderate medium sub angular blocky, m1sbk- moderate weak sub angular blocky, c3sbk- coarse strong sub angular blocky, f2sbk- fine medium sub angular blocky, f1sbk- fine weak sub angular blocky; fr.ss.po- friable, slightly sticky and non plastic consistency, fr.ss.sp- friable, slightly sticky and slightly plastic consistency, fi.s.p- firm, sticky and plastic, fi.ss.p- firm, slightly sticky and plastic, fi.s.p- firm, sticky and plastic; f1f- few fine faint mottles, f1p- few fine prominent mottles, m2p- common medium prominent mottles; es- strong effervescence, ev- violent effervescence; WD- well drained, MWD- moderately well drained, PD- poorly drained.

Table 2. Particle size distribution as influenced by cropping systems and pedons.

Results	Sand (%)	Silt (%)	Clay (%)
Cropping systems			
Plantation	1.5[c]	59.7[a]	38.8[b]
Paddy-potato	19.9[a]	52.9[a]	27.1[c]
Paddy-paddy	9.4[b]	37.7[b]	53.6[a]
LSD	2.49	6.61	7.23
Pedons			
Epipedon	16.4[a]	49.5[ab]	34.1[a]
Endopedon1	14.1[ab]	43.9[b]	41.9[a]
Endopedon2	9.8[c]	51.4[ab]	39.1[a]
Endopedon3	11.1[c]	52.4[a]	37.2[a]
LSD (P<0.05)	2.81	7.63	8.35

*means followed by same letter within the column are not significantly different at P<0.05.

Table 3. Water retention characteristics as influenced by cropping systems and pedons.

Results	Field capacity (%)	Permanent wilting point (%)	Available water content (AWC) (%)
Cropping systems			
Plantation	24.51[b]	12.39[b]	12.11[a]
Paddy-potato	20.08[c]	8.95[c]	11.12[a]
Paddy-paddy	25.71[a]	16.77[a]	8.90[b]
LSD (P<0.05)	1.00	1.45	1.33
Pedons			
Epipedon	23.52[ab]	11.83[b]	11.65[a]
Endopedon1	22.61[bc]	12.98[ab]	9.67[b]
Endopedon2	24.52[a]	14.14[a]	10.34[b]
Endopedon3	23.55[ab]	12.68[ab]	10.85[ab]
LSD (P<0.05)	1.15	1.68	1.00

*means followed by same letter within the column are not significantly different at P<0.05

the year. Continuous submergence of the soil creates significant changes in the physical, chemical and morphological properties of the soil. The coarse strong sub angular blocky structure in the paddy-paddy cropping system was due to the intensive cultivation with mechanized tillage for the last three decades (Jung et al., 2010).

Soil physical properties

Results on particle size distribution are presented in Table 2. There was a significant variation in particle size distribution under soils of different cropping systems. Highest clay content was recorded in paddy-paddy cropping system (53.6%) and highest sand content (19.9%) was recorded in paddy-potato cropping system. The high sandiness in paddy-potato cropping system is due to continuous cropping and intensive tillage which leads to loss of fine material from the system whereas continuous puddling increases the clay content in paddy-paddy cropping system. High silt content in thirty-five year old plantation system attributed to dense cover which helps to suppress soil erosion. Deekor et al. (2012) and Kauffmann et al. (1998) found similar results of increase in silt content in plantation soils is due to development of dense cover.

Significant differences in available water content were observed between different cropping system and pedons (Table 3). Soils of paddy-paddy cropping systems retained significantly higher water both at field capacity (25.71%) and permanent wilting point (16.77%).

Table 4. Soil properties influenced by cropping systems and pedons.

Results	OC (%)	pH_w	EC (dSm^{-1})	CEC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}
				(c mol (p+) kg^{-1})				
				Cropping systems				
Plantation	0.42^a	6.69^b	0.18^a	14.02^b	10.60^a	1.62^a	0.46^b	0.20^a
Paddy-potato	0.33^b	6.32^b	0.19^a	11.89^b	5.85^b	1.29^b	0.31^c	0.10^b
Paddy-paddy	0.36^a	7.14^a	0.18^a	17.85^a	9.40^a	1.50^a	0.85^a	0.26^a
LSD (P<0.05)	0.09	0.43	0.04	1.23	1.24	0.19	0.15	0.08
				Pedons				
Epipedon	0.84^a	6.26^b	0.21^a	13.19^a	7.11^b	1.28^b	0.43^b	0.20^a
Endopedon1	0.29^b	6.58^{ab}	0.15^b	13.74^a	7.63^a	1.44^a	0.50^a	0.16^a
Endopedon2	0.20^c	6.85^a	0.16^{ab}	14.23^a	8.53^a	1.46^a	0.65^a	0.19a
Endopedon3	0.19^c	7.03^a	0.16^{ab}	13.79^a	7.66^a	1.37^a	0.51^a	0.18^a
LSD (P<0.05)	0.11	0.49	0.05	1.42	1.11	0.15	0.16	0.06

*means followed by same letter within the column are not significantly different at P<0.05

Significantly lower water retention was observed in both field capacity and permanent wilting point by soils of paddy-potato cropping systems. Plantation system has recorded highest available water content (12.11%), which is significantly higher than paddy-paddy cropping systems (8.90%). Higher AWC in Plantation system can be ascribed to favorable structural properties (Emadi et al., 2008) and high organic matter (Bauer and Black, 1992). In Plantation system, the high organic matter from decomposed leaf fall creating high AWC whereas high clay with unfavorable structure leads to low AWC in paddy-paddy cropping system. These results confirmed that land use systems have a greater effect on water retention in soils (Haghighi et al., 2010; Wall and Heiskanen, 2003; Li et al., 2007). Epipedon recorded significantly higher available water content than endopedons 1 and 2 which is due to high organic matter and favourable structure.

Soil chemical properties

A perusal of data in Table 4 showed that pH of soils of paddy-paddy cropping system is neutral in nature (7.14) whereas soils of paddy-potato cropping system are slightly acidic (6.32). The low pH in paddy-potato cropping system was due to removal of basic cations by cation loving crops during biomass harvesting (Marcar and Khanna, 1997) and accelerated leaching of bases from the soils by rainfall. The soil reaction of epipedon is slightly acidic compared to endopedon which is due to continuous cation uptake by plant, with subsequent release of H^+ ions, organic matter decomposition into organic acids, increased CO_2 levels through root respiration and nitrification (Juo and Manu, 1996). Epipedon recorded significantly lower pH compared to endopedon 2 and 3 and on par with endopedon 1. The general increase in pH down the profile was due to increase in basic cations. There is no significant difference in electrical conductivity observed with respect to cropping system whereas significantly higher electrical conductivity recorded in epipedon compared to endopedon 1.

The cropping systems and pedons significantly differed in organic carbon content. The highest organic carbon mean values recorded in Plantation system (0.42%) which is statistically on par with paddy-paddy cropping system (0.36%) whereas paddy-potato cropping system recorded significantly low organic carbon content (0.33%). Organic carbon decreases with increasing pedal depth. Significantly highest organic carbon recorded in epipedon compared to endopedon. The higher organic carbon detected in plantation system was probably as a result of accumulation of litter from continuous residue addition or absence of soil disturbance for an extended period (Manjoke et al., 2007) and increased carbon input through addition of root biomass by wetland paddy cultivation in paddy-paddy cropping system. Contrary to this, intensive tillage operations, crop residue burning and relatively lower amount of organic matter additions kept low organic carbon in paddy-potato cropping system (Senthilkumar et al., 2009).

The cation exchange capacity (CEC) of soil in plantation system, paddy-potato and paddy-paddy cropping system was 14.02, 11.89 and 17.85 c mol (p+) kg^{-1} respectively. The results of analysis of variance showed that significantly higher CEC was recorded in soils of paddy-paddy cropping system and paddy-potato cropping system recorded lower CEC which is statistically on par with plantation system. The higher CEC in paddy-paddy cropping system is due to presence of high clay content and lower CEC in paddy-potato cropping system

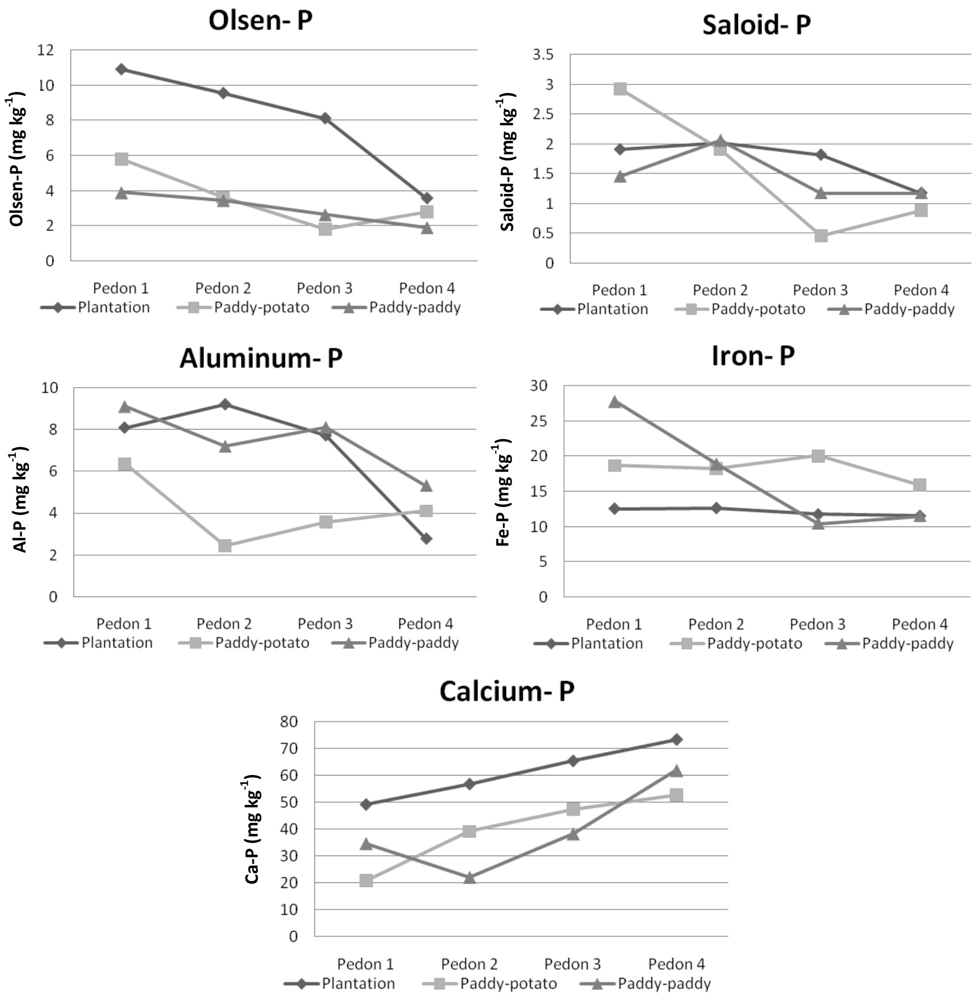

Figure 3. Influence of cropping systems on different Phosphorus fractions.

was due to the intensive cultivation and lower soil organic carbon content. Geissen et al. (2009) also found that intensive annual crop cultivation leads to very low CEC. The difference in CEC between pedons is limited. Results of exchangeable cations showed that exchangeable calcium dominated the exchange site among the basic cations in all the cropping systems. Paddy-potato cropping system recorded significantly lower exchangeable cations compared to other system. Epipedon recorded significantly lower exchangeable calcium, magnesium and sodium than endopedons. Deekor et al. (2012) opined that both clay and organic matter serve as potential sources of nutrients by attracting cations as such, soils with large amounts of clay or organic matter have higher exchange capacities than sandy soils.

Phosphorous fractions

Maintenance of adequate amounts of soil phosphorous (P) is critical for long term agricultural productivity. The amount and distribution of various forms of inorganic phosphorous in different cropping systems are presented in Figure 3. The relative abundance of inorganic P forms in the soil was generally Ca-P>Fe-P>Al-P>Saloid-P. Higher amount of Olsen-P (extracted by $NaHCO_3$) was recorded in plantation system (10.91 mg kg^{-1}) followed by paddy and paddy-potato cropping system. Soils of plantation recorded high Calcium-P (extracted by 0.5 N H_2SO_4) whereas paddy-paddy cropping system recorded higher Al-P (extracted by 0.5 N NH_4F) and Fe-P (extracted by 0.1 N NaOH) which is due to continued submergence. Patrick and Mahapatra (1968) found that poorly drained soils have larger quantities of Al-P and Fe-P compared well drained and moderately well drained soils. Srivastava and Pathak (1971) found that water-logged area had comparatively lower amounts of adsorbed phosphate and calcium phosphate and contained proportionately higher values of iron and aluminium phosphate. Epipedons recorded high Olsen P compared to endopedon irrespective of cropping

Table 5. Results of the two-way analysis of variance in important soil properties under the two cropping systems and four pedons.

Factors	df	Sand	silt	clay	OC	pH	EC	CEC	FC	PWP	AWC
Cropping systems	2	0.00	0.00	0.00	0.00	0.00	0.58	0.00	0.00	0.00	0.00
Pedons	3	0.15	0.45	0.49	0.00	0.02	0.14	0.93	0.04	0.11	0.07
Cropping systems × Pedons	6	0.78	0.64	0.58	0.71	0.98	0.66	0.82	0.19	0.52	0.12

systems. Generally, Olsen-P decreased with depth whereas calcium-P increased with depth. Higher P fractions were found from the Plantation system than the cultivated fields which may be ascribed to the active biocycling of phosphorous due to the presence of perennial plant and better crop management (Solomon et al., 2002). Daroub et al. (2001) found that the effect of perennial cropping system on soil P fraction was more apparent than annual cropping system.

The results of two way analysis of variance (Table. 5) showed that cropping system is a significant factor in determining most of the important soil properties significantly ($p < 0.05$) except electrical conductivity. Organic carbon, pH and water retention at field capacity which differed by both cropping system and pedons. The interaction between these two factors had not significantly affected any of the soil properties.

Conclusions

It is concluded that there exists a strong relationship between soil properties and cropping systems. The degradation of these soil properties can negatively affect soil productivity. Identifying, quantifying and monitoring these changes are necessary to prevent soil degradation and to improve soil and land management. To prevent further degradation, it is expedient to generate appropriate environmentally friendly soil management techniques suitable for each cropping system like proper drainage system, soil test based fertilizer application in paddy-paddy cropping system, addition of organic matter, lime and crop rotation with pulses in paddy-potato cropping system, in order to enhance soil fertility and sustain food production.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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Potentiality of a desert plain soil to irrigation in River Nile State-Sudan

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In this research GPS (Garmin-GPSmap276C) was used to locate the observation sites and explore potentiality of soils of the area east of Shendi town, Shendi Province-River Nile, State of Sudan which is about 12751 ha and comprises a flat to slightly undulating desert plain with low gravely ridges and low jebels in south western and north western parts for irrigated agriculture in terms of the suitability of the landscape and associated soils to the desired use. Map was prepared in the office with 500 m × 500 m grid, the soils were mapped at this intensity and soil lines were drawn to locate the soil profiles at approximately the centre of every delineation. Results revealed least one soil profile for every unit that has an 840 ha was described following FAO (2006) format for profile description and was sampled at different soil horizons. The profiles and auger observation samples were subjected to analysis for their chemical and physical properties. The chemical and physical characteristics was further used to fine tune the soil boundary lines, and for final classification and evaluation purposes for the intended land utilization types. Soil classification was done using USDA Soil Taxonomy (1999) and Keys to Soil Taxonomy (2010), while the evaluation was done following Kevie and Eltom (2004). Hence soil and suitability maps were the final product. Results of this study revealed that 22.9% of the soils of the area were moderately suitable, 69.6% are marginally suitable, 1.6% are currently unsuitable while 5.9% are permanently unsuitable for irrigated agriculture.

Key words: Potentiality, desert plain, River Nile, irrigation.

INTRODUCTION

This study was carried out to fulfil the main objectives which are: the characterization of soils and landscape; assessment of the suitability of the land for irrigated agriculture and to provide guidance to agronomists and irrigation engineers. The main landform is the desert plain. The area is flat, slightly sloping northeast towards Wadi Elhawad and very slightly sloping northwest. Except for low gravelly ridges and low jebels (hills) in south western corner of the project and the low very few scattered gravelly ridges the whole area can be seen as flat to slightly undulating desert plain.

The solid geology that underlies the unconsolidated mantle is of Precambrian Basement complex which crops out in the south western boundary, Cretaceous age represented by Nubian sandstone which is supposed to be the parent material for all the soils in the area and

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Table 1. Main climatic features of Shendi Meteorological Station, 2001-2010.

Climatic features	January	February	March	April	May	June	July	August	September	October	November	December
Maximum temperature (°C)	30	32	36	40	41	41	38	36	38	38	34	30
Minimum temperature (°C)	14	16	19	22	26	28	26	26	27	25	19	15
Precipitation (mm)	trace	trace	trace	0.2	1.8	4.2	20.7	39.3	9.2	2.2	0.0	0.0
Wind Direction (from the)	NE	NE	NE	NE	NE	SW	SW	SW	SW	NE	NE	NE

http://www.wunderground.com/history-2010.

quaternary age formations in the form of Nile alluvium and aeolian deposits (GRAS, 1988). The area lies within the desert plain landscape. Wind erosion is an important feature in the area where processes of deflation and deposition are active. In the southern parts close to the hills or Jebels, sand ripples are common features indicating a deflation process, whereas, to the north and north western parts deposition in the form of sand hummocks around the trees and tumam is common. The climate of area is the hot continental desert climate with annual rainfall of less than 200 mm and <0.5 wet months, the relative humidity is <40% and large diurnal and annual temperature range. The main activity is pastoralism and cultivation through irrigation (Walsh, 1990).

According to Adam (2002), the climate of the area is semi-desert, confirming earlier classification of the area as semi-desert by Kevie (1976). The summer months starts from April and end in September with rainfall in July and August and winter months from October to March. The cool winter in the region is an important factor when considering crop selection. Table 1 shows the main features of the climate of the area represented by Shendi Meteorological Station.

The soil temperature and moisture regimes according to Wambeke (1982) are hyperthermic and aridic using Shendi climatic data. Previous ecological classifications in Sudan by Wickens (1990) classified the area as semi desert scrub and grassland on basement complex soils. The vegetation is very sparse and concentrated in sites where moisture is available in water courses (wadies and khors). The main vegetation types are: Salam (*Acacia ehrenbergiana*), Samar (*Acacia tortilis*), Hegleig (*Balanites aegyptiaca*), Tumam (*Panicum turgidum*) *and* Gaw (*Aristida funiculata*).Earlier studies on land evaluation underscore its importance in assessing land potentials for a specific purpose as well as understanding its optimal requirement. Land evaluation can be carried out to understand land potentials for a particular purpose at whatever scale (e.g. local, national, regional and even global). According to George (1997), studies

at the national scale may be useful in setting national priorities for development, whereas those targeted at the local level are useful for selecting specific projects for implementation. Land evaluation is applicable both in areas where there is strong competition between existing land uses in highly populated zones as well as in zones that are largely undeveloped. FAO (1983, 1995) noted that for assessing the suitability of soils for crop production, soil requirements of crops must be known and understood within the context of limitations imposed by land form and other features which do not form a part of the soil but may have a significant influence on use that can be made of the soil. A number of soil characteristics are directly related to crop yield and performance; beyond critical ranges, crops cannot be expected to yield satisfactorily unless special precautionary management measures are taken.

Soil suitability classifications are therefore based on knowledge of crop requirements, of prevailing soil conditions and of applied soil management. In other words, to the extent soil conditions match crop requirements under defined management and inputs (FAO, 1976).

MATERIALS AND METHODS

This research used GPS to locate the observation sites and explore potentiality of soils of the area east of Shendi town, Shendi Province-River Nile, State of Sudan which is about 12751 ha and comprises a flat to slightly undulating desert plain with low gravely ridges and low jebels in south western and north western parts for irrigated agriculture in terms of the suitability of the landscape and associated soils to the desired use. The climate is semi-desert with summer rains and cool winter; while the soil temperature and moisture regimes are hypethermic and aridic respectively. Field survey was located by GPS and adhered to a basic 0.5 km × 0.5 km grid. The intensity of field survey was one soil auger observation per 60 feddans.

Sample collection and classification and analysis

In all, 507 augers and 6 profile pits were made. At 125 auger sites, soil samples were collected from the 0.0 to 0.25, 0.25 to 0.50 m depths for pH, salinity (EC) and sodicity (SAR) screening. Five infiltration tests (double-ring infiltrometer method) were done at five locations with each test replicated thrice. A total of 33 soil samples were collected from the soil profile pits, profiles were described following FAO (2006) format for profile description, sampled at different soil horizons and classified according to the USDA Soil Taxonomy (1999) and Keys to Soil Taxonomy (2010). The profiles and auger observation samples were subjected to analysis for their chemical and physical properties following methods outlined by Page (1982) and Klute (1986). The chemical and physical properties were further used to fine tune the soil boundary lines,

Table 2. The main soil units.

Mapping unit	Soil name	Description
10	Eddamer	Deep to moderately deep soil, olive brown and/or dark greyish brown, sandy clay loam, non-calcareous,
20	Kelli	Moderately deep, reddish brown and/or dark yellowish brown, sandy clay loam, non-calcareous, the surface is covered by sand ripples or sand sheet and few gravels.
21	Kelli gravely	Moderately deep to shallow, reddish brown and/or yellowish brown, sandy clay loam, with gravels on the surface and embedded in the profile.
30	Infilled Wadi	Dark reddish brown, sandy or sandy loam soils with a thick mantle of sand hummocks around tumam and salam
M	Miscellaneous	Gravelly ridges

Table 3. Soil classification and correlation.

Order	Sub order	Great group	Sub-group	Family	Soil series	Phase
	Cambids	Haplocambids	Typic Haplocambids	Fine loamy, mixed, hyperthermic	Eddamer	
Aridisols	Argids	Haplargids	Typic Haplargids	Fine loamy over loamy skeletal, mixed, hyperthermic	Kelly	
	Argids	Haplargids	Typic Haplargids	Fine loamy, mixed, hyperthermic	Kelly	Gravely
Enttisols	Psamments	Torripsamments	Torripsamments	Sandy mixed, hyperthermic		

and for final classification and evaluation purposes for the intended land utilization types; hence soil and suitability maps were the final product.

Sample identification and evaluation

Two orders (Ardidsos and Entisols) and three main suborders of soils are identified: Argids Cambids and Psamments. The Argids (brown soils) covered about 23%, the Cambids (red soils) about 70%, and Psamments about 7%. Land suitability assessment follows the Framework for Land Evaluation adapted for Sudan by Kevie and Eltom (2004). It is based on the analysis of a number of sites and soil characteristics matched against the requirements of the intended land use, termed land utilization types (LUT). The proposed agricultural development plan is intended for both surface and pressure irrigation systems. The land suitability has two orders: Suitable (S) with highly (S1), moderately (S2) and marginally (S3) suitable classes; and unsuitable (N) with currently (N1) and permanently (N2) unsuitable classes.

RESULTS AND DISCUSSION

The whole area lies within the desert landscape, so the soils were categorized into three main groups namely, the brown soils, the red soils and soils of infilled wadis. The brown soils surface is always covered with gravel and sand sheet, mostly devoid of any vegetation, except in some low lying patches as resembled by Eddamer soil series, while the red soils (Kelli soil series, Kelli gravely phase and miscellaneous landtype) are soils of gravelly ridges, covered by gravel and sand ripples and sometimes the gravels are embedded in the soil column and finally the soil of Infilled wadis are covered by thick mantle of sand hummocks around *Panicum tugidum* and *Acacia ehrenbergiana*.Three main soil units were identified with one phase and one miscellaneous land type associated with them (Table 2). Mostly all soils properties along with their chemical and physical properties were considered to classify the soils using USDA system of classification (USDA, 1999; Keys to Soil Taxonomy, 2010). The soils were then correlated with the established soil series in LWRC as shown in Table 3.

The brown soils are flat or slightly convex, devoid of any vegetation. The surface is covered in some places with fine calcium carbonate concretions, while the red soils occupy a relatively high position in the pediment plain. The soil surface is flat with sand ripples and few quartz gravel. On the other hand, the soils of infilled wadi are characterized by a thick cover of wind blown sand. It has a dense vegetation cover of tumam (*P. turgidum)*, salam (*A. ehrenbergiana)* and higleig (*Balanites aegyptiaca*) trapping the blowing sands. The brown soils are deep, moderately drained while the red are moderately deep and moderately well drained. All soils are non-saline and non-sodic with ECe of less than 4 dS/m and ESP of less than 15, although previous studies reported saline and sodic spots in adjacent areas (Fadul, 1990). The infilled wadi and the miscellaneous land type are not recommended for agricultural use; although the infilled wadi soils could be used, it is advised that they be left as barrier to trap the moving sands.

A minimum of 2.0 m soil depth is required for areas where there is salinization or risk of salinization to allow for leaching or drainage if needed which is not the case here as all soils are non-saline.

Surface irrigation requires gently smooth sloping deep medium and fine textured soils, so gravely and coarse textured soils with infiltration rates above 60 mm/h are not suitable, unless very short furrows or very short basins are used, which is not desirable, this indicates that all soils here are not suitable for surface irrigation Table 4

Table 4. Infiltration rate for all soil units.

Profile number	Soil unit	Soil texture	IR (cm/h)
GP01	10		6.80
GP02	20		18.30
GP03	20		7.00
GP04	21		8.56
GP06	10		6.50

Table 5. Available water content per soil unit.

AWC class	Average	Range of average values	Range of average for mapping units	Mapping units	Suitability for irrigation
High	182	> 170			All types
Moderate	139	131 – 170	130-137	10	All types
Low	116	90 – 130	91-123	20-21	Sprinkler. Marginal for Gravity, Drip
Very low	74	< 90			Not suitable

Sandy and steep sloping soils of up to 20% slopes can be used for sprinkler irrigation, hence soils suitable for sprinkler irrigation are not suitable for surface, while the reverse is true.

Drip or micro-sprinklers are restricted to small areas where high value crops, that is, fruits, flowers and vegetables are grown. There is less hazard of rising water table or salt mobilization compared to other irrigation forms. It can not be used in sandy or very gravelly soils.

Of particular importance to the choice of irrigation system are hydraulic conductivity, infiltration rate and available water holding capacity, and they should be considered.

Table 4 show the infiltration rate (IR) for the soils of the area and the results show that the infiltration rate is above 6.0 cm/h, hence the soils are increasingly marginal for successful gravity irrigation, regarding the hydraulic conductivity, the permeability is rapid having values more than 0.3 m/day (Landon, 1991).

The available water capacity (AWC) according to soil units is shown in Table 5. Given that in desert zones where there is little accumulation of organic matter and where soil structures tend to be weakly developed, AWC is primarily related to soil texture. This varies considerably within and between soils so there is a corresponding variability of AWC as evidenced by the disparity between minimum and maximum values per soil unit. Based on all the survey data arranged per soil unit the following classification of AWC has been derived Table 5.

Sandy and coarse loamy soils that have low or very low AWCs are marginally suitable or unsuitable for gravity irrigation. It is to be remembered that not all of the soil AWC is readily available to plants. Readily available water content was not measured, but a rule-of-thumb is that it is about half to two-thirds of the total AWC (Landon, 1991).

The relevant land qualities that should be considered in analysis for irrigated agriculture in general have been listed by Kevie and Eltom (2004). The limits of suitability for each land quality have been followed in this study but with necessary adaptations to cater for the different requirements of surface and pressure irrigation as Land Utilization Type (LUT). Table 6 sets out the minimum requirements to separate suitable from non-suitable land under different irrigation regimes. For land to be suitable, all the criteria must be met.

None of the soils of survey area is highly suitable (class S1) for the LUTs being considered. Most of these soils are flat land and are suited to both surface and sprinkler irrigation and can sustain a wide range of crops. They are at best suited as class S2.

The coarse-textures, soil depth and/or topography are the main parameters that can reduce productivity and/or increase production costs and thereby downgrade land to classes S3, N1 or N2. Such land anyway is unsuitable for surface irrigation. Coarse soils demand more irrigation and sloping land may limit the options for pressure irrigation systems or affect their efficiency.

By comparing the soil and site characteristics against the aforementioned suitability criteria we have recognized four main categories of land suitability suborders, S2, S3, N1 and N2. These are defined in Table 7 and shown in Figures 1 and 2. Suitability subclasses are defined by the relevant *limitation* to use, where d = soil depth limitation, g = gravel limitation, m = soil moisture limitation (low AWC and/or high infiltration rate due to coarse soil texture and/or many gravels), t = topographic limitation and e= wind erosion limitation. These limitations may

Table 6. Measured land and soil characteristics; minimum value to establish land suitability for irrigated agriculture.

Characteristics	Surface	Sprinkler	Drip
Landform	Any except jebel, kerib, khor, floodplain		
Topography	Flat – gently undulating, long smooth slopes	Flat to rolling but excluding badlands	Flat to undulating but excluding badlands
Slope	< 3%	< 20% [1]	< 8%
Erosion	Exclude severe; that is, > 50% of area with one or more of dunes; hummocks > 0.4 m; gullies > 0.5 m deep		
Flooding	Exclude floodplain land inundated annually by main rivers		
Soil depth	> 2.0 m	> 2.0 m[2]	> 1.0 m
Sandy / gravel cover	< 0.15 m	n/a	n/a
Topsoil (0 - 0.25 m) stone, gravel	< 40% volume		
Topsoil (0 - 0.25 m) texture	Loamy or clayey (that is, not sandy, not gravely (>15%) loamy)	Any	Loamy or clayey (that is, not sandy, not gravely (>15%) loamy)
Infiltration rate[3]	1 – 60 mm/h	> 1 mm/h	> 1 mm/h
AWC, top m	> 90 mm	> 50 mm	> 90 mm
Permeability rate	> 8 mm/h (0.2 m/day)		
Soil drainage class	Any except very poor (and poor if drainage is not feasible)		
Water-table depth	> 3.0 m (or >1.0 m if drainage is feasible)		
Cation exchange capacity	> 8.0 $cmol^{(+)}$ kg^{-1} (or < 8 if extra fertilization is feasible)		
pH, top m	< 9.0 (or > 9.0 if associated with sodicity where reclamation is feasible)		
EC, top m	< 16 (or > 16 if reclamation is feasible) dS/m		< 4 dS/m
ESP / SAR, top m	< 35; < 50 for Vertisols (or higher if reclamation is feasible)		< 15

i) Based on criteria for centre-pivot irrigation. Other sprinkler systems are restricted to slopes < 15%.
ii) 1.5 m with proven well-managed centre-pivot irrigation and no evidence or risk of rising water-table or salinisation.
iii) Italicised parameters are measured from soil profile analyses or site tests. Non-italicised parameters derive from soil auger survey. Soil depth is measured from auger and profile pit.

Table 7. Land suitability classification.

Land suitability		Area (ha)	%
Suitable land			
Moderately suitable land			
S2def	Moderately severe limitations for the proposed uses and management. The land is flat or almost flat. Soils are deep to moderately deep. The main limitation being gravel, soil depth and wind erosion (MU10)	2923	22.9
Marginally suitable land			
S3dgm	Severe limitations due to shallow soil depth, gravel and moisture deficiency (MU 20&21)	8870	69.6
Unsuitable land			
Currently not suitable			
N1edm	Very severe limitations due to severe wind erosion , sandy soil texture and moisture deficiency. This land should be left as shelter belt to trap the creeping sands. (MU30)	202	1.6
Permanently not suitable			
N2	Gravely ridges (MU-Miscellaneous)	756	5.9
Total		12751	100

lower the profitability of the LUT being considered and/or may demand particular management, but they are surmountable as part of adapted farming practices.

Normal farming practices would be expected to cope with calcareous soils and somewhat gravely soils. Rough micro topography would be smoothed and surface stones

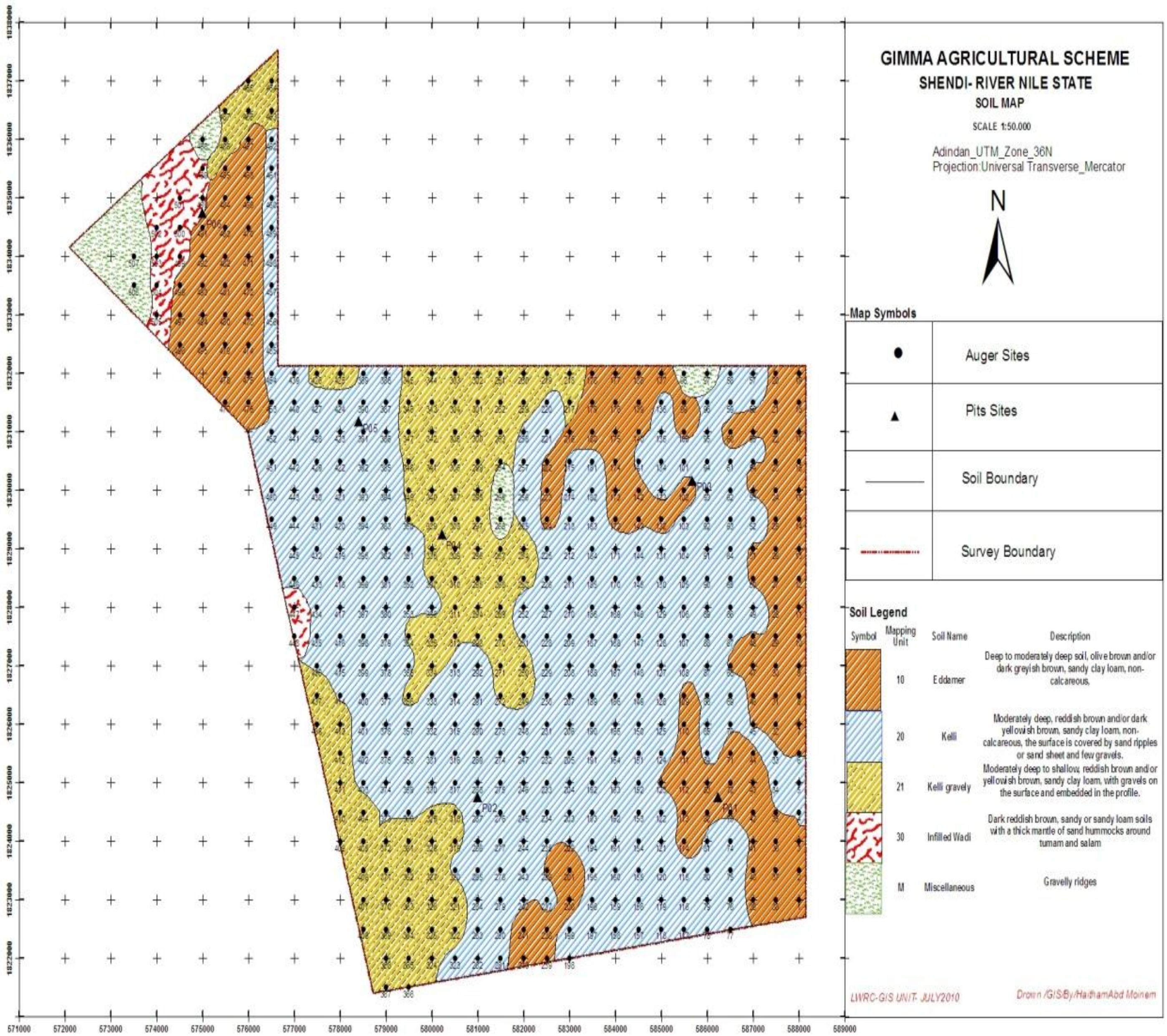

Figure 1. Soil map.

scraped away during land preparation, albeit with an increased cost.

Limitations and remedies

The main limitations in the study area are: shallow soil depth, erosion hazards, low soil fertility, high gravel content and moisture deficiency. The major remedies are:

i) Addition of fertilizers.
ii) Wind breaks and shelter belts for protection from wind erosion.
iii) Scraping of surface gravel and leveling.
iv) Addition of organic manure as a fertilizer and amendment.

Conclusions

The study thus revealed that
i) 23% of the total area is moderately suitable for irrigated agriculture.
ii) 70% of the total area is marginally suitable for irrigated

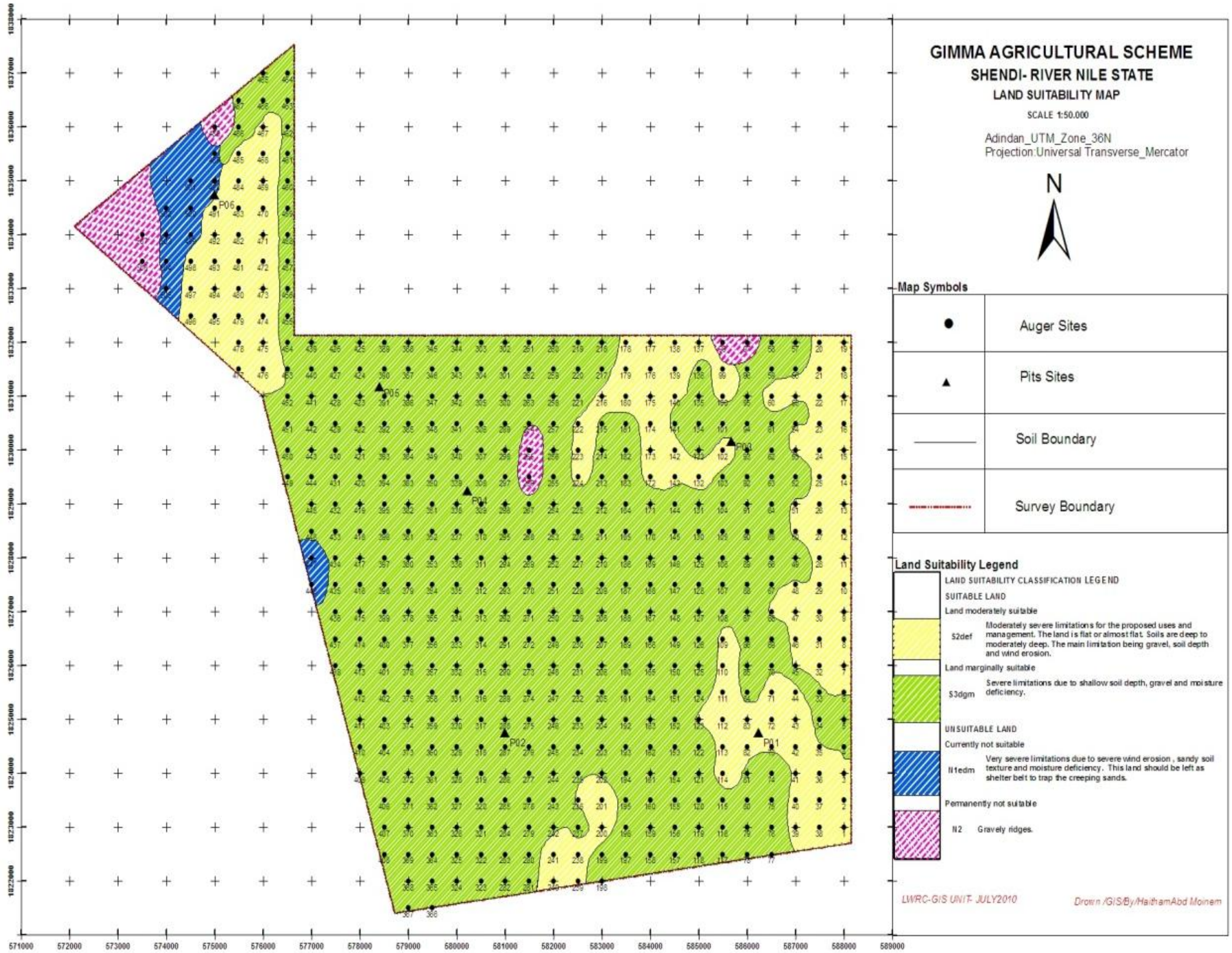

Figure 2. Land suitability map.

agriculture.

iii) 1% of the total area is currently unsuitable for irrigated agriculture.

iv) 6% of the total area is permanently unsuitable for irrigated agriculture.

Therefore, as infiltration rate is above 6.0 cm/h, the soils are increasingly marginal for successful gravity irrigation; also regarding the hydraulic conductivity, the permeability is rapid having values more than 0.3 m/day.

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Full Length Research Paper

Production of a novel bioformulation of *Trichoderma/Hypocrea* using biotechnological approaches

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Seven different strains of *Trichoderma* isolated from wilt infected legume fields of UP State were tested for their antagonistic activity against *Fusarium* (soil borne pathogen), which is expressed as a zone of inhibition in the culture plates. Seven strains were identified as *Trichoderma viride, Trichoderma harzianum, Trichoderma asperellum, Trichoderma koningii, Trichoderma atroviride, Trichoderma longibrachiatum* and *Trichoderma virens*. Upon successful identification, morphological description and sequencing of the isolated strains with the help of universal Internal transcribed spacer (ITS) primers, the sequences are submitted to NCBI and allotted with the accession numbers JX119211, KC800922, KC800921, KC800924, KC008065, JX978542 and KC800923, respectively. Mycoparasitism is an inherent ability of the genus *Trichoderma* that involves the role of cell wall degrading enzymes such as xylanase, glucanase, chitinase, and proteinase etc. and acting as a biocontrol agent. This study reports the xylanase enzyme activity for all the isolated strains on a media containing birchwood xylan as a carbon source where *T. harzianum (Th* Azad), could show maximum activity there upon acting as a strain of utmost importance to the farmers for protecting their crops against wilting. Genetic variability within different strains of the same species was also analyzed to develop a novel strain possessing competitive ability, growth promoting characters and inducing resistance in plants. A percentage of polymorphism in Simple sequence repeats (SSRs) is obtained within the seven strains of *Trichoderma* species, which is comparatively higher (>77%) than with Random amplified polymorphic DNA (RAPD) primers (~50%). The study aims at exploring *Trichoderma* species and then preparing a simple bioformulation that is cheap, easy to apply and readily accessible to the farmers. The shelf life of *Trichoderma* in the prepared bioformulation is even checked for 180 days and it is concluded that the number of propagules start declining from 30th day onwards when the bioformulation is prepared in talc as a carrier material. It was also found that seed treatment with the bioformulation *T. harzianum* (*Th* Azad) (5 g/kg seeds) could increase seed germination, root and shoot length and seedling vigour over untreated ones.

Key words: Antagonism, bio-control agent, *Trichoderma*, shelf life, polymorphism, genetic variability.

INTRODUCTION

The genus *Trichoderma* has its own significance in the agricultural industry due to its varied activities ranging from being a valuable antagonist against the soil-borne pathogens to acting as a provider of nutrition to the soil as well. Several scientists have worked on how this genus acts as a potential biocontrol agent against a range of pathogenic fungi. Harman et al. (2004) have even reported *Trichoderma* as opportunistic, avirulent plant symbionts. They have explained the features of *Trichoderma* as to how it colonizes the roots that eventually proves beneficial to the soil in terms of nutrition and plant growth increasing crop productivity simultaneously.

The biocontrol activity of *Trichoderma* is of immense importance not only to agriculture and its crops but also the environment as it does not accumulate in the food chain and thus does no harm to the plants, animals and humans (Monte and Llobell, 2003). The genes and gene products involved in the biocontrol mechanism of *Trichoderma* provide a vast array of research to the scientists in biotechnology and bioinformatics as well.

Various strains of *Trichoderma* have been isolated and identified till date in an attempt to investigate the morphology, molecular characterization, phylogeny, taxonomy, mode of action, enzymatic activity, antagonistic activity, bioformulation, etc. which has opened the gates of new research on this topic. Most ongoing research is aimed at developing new techniques or strains that can prove ecologically beneficial to the agriculture.

The intrageneric classification by Bisset (1991) shows significant morphological similarities between *Trichoderma* and *Hypocrea* and have defined genus *Trichoderma* to include the anamorphs of *Hypocrea*.

The morphology of *Trichoderma* sp. is very interesting to study as there are a finite number of morphological descriptors to study and disseminate the genus and its features (Gams and Bissett, 1998; Gams and Meyer, 1998). It is believed that the identification of any microorganism becomes quite easy by a careful morphological observation; hence, a detailed morphological description of some of the commercially important strains of *Trichoderma* has been carried out in this study. Samuels (2006) described the systematics, the sexual stage and the ecology of *Trichoderma* and mentioned in his study that the morphology of *Trichoderma* is not only limited to a few characters but many species may be included in this genus due to their geographical distribution.

Isolation, characterization and morphological description of *Trichoderma* species are important before further dissemination is done leading to the biomass production at different environmental and cultural conditions. An attempt has been made to grow different species of *Trichoderma* at varying pH, temperature and agitation speeds in order to reveal all the relevant and favorable parameters.

The isolates from the soils of legume fields are more adaptive to the tested pH ranges than the isolates from virgin soils where there is no intervention of agricultural practices. As *Trichoderma* is an ecofriendly biological control agent (BCA) against other soil borne plant pathogens, it is necessary to grow it at suitable conditions before it is used for commercial purposes. Different pH, temperatures and agitation speeds have been tested in this study for a better growth of different isolates of *Trichoderma* species.

Druzhinina and Kubicek (2005) studied and brought forth the species concepts and biodiversity in *Trichoderma* and *Hypocrea* by aggregating the morphological, physiological and genetic studies and presented an update on the taxonomy and phylogeny of a number of taxa. This helped us in understanding that the identification of *Trichoderma* only on the basis of morphology is not of high precision. Thus, molecular identification and characterization comes under investigation that would help in evaluating the genetic diversity between the species.

Kumar et al. (2011), Shahid et al. (2012a) and Sagar et al. (2011) focused on the molecular identification and analysis of the genetic variability of a specific strain of *Trichoderma* based on antagonistic and Random amplified polymorphic DNA (RAPD) analysis in some leguminous crops (pigeonpea, chickpea and lentil) produced in Uttar Pradesh (India). RAPD analysis with a set of 20 OPA primers was carried out on 5 isolates of the same species (*Trichoderma longibrachiatum*) collected from different soil samples of pigeon pea. This resulted in a significant amount of genetic variability where more than 50% of the amplified fragments in each case were polymorphic. Thus, it was concluded that there was good genetic variability among the isolates under study.

Based on the genetic variability studies done earlier, the study now was focused upon developing a strain-specific molecular marker solely for the identification of *Trichoderma* species. rRNA based analysis is thought to be the best one to explore the microbial diversity and identify new strains (Shahid et al., 2013).

The genus *Trichoderma* is well known among the microbial world as BCA and this is due to the presence of certain specific cell wall degrading enzymes such as chitinases, glucananses, proteinases, xylanases, etc. to name a few. Each enzyme has its own role in mycoparasitism thus, it becomes important to study the activity of such enzymes produced by *Trichoderma* species. The induction of xylanase from *T. harzianum* (*Th* Azad) by using different carbon sources was studied by Singh et al. (2012b). Highest xylanase activity (5.8 ±0.01 IU/ml) was observed at 120 h with 1% birchwood xylan as a carbon source.

The study also includes the behavior of these BCAs

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against fungal wilt pathogens affecting leguminous crops (lentil, pigeonpea and chickpea). The strains distribution in several genotypes could also support the idea of developing antifungal formulations in which different *Trichoderma* BCAs could be combined. But, before preparing a bioformulation with *Trichoderma*, the effect of media, temperature and pH on the growth and sporulation of *Trichoderma* species should be known (Singh et al., 2011; Shahid et al., 2011). *Trichoderma* species, when grown either in Potato dextrose agar (PDA) or Potato dextrose broth (PDB) within a pH range of 7 to 7.5 and at an optimum temperature range of 25 to 30°C gives the best growth and sporulation rates both.

Talc-based bioformulation of *Trichoderma* (Shahid et al., 2012c) has proven beneficial to the wilt infected leguminous crops but an important aspect to be taken into prior consideration is the shelf life of spores that are present in talc. Various methods and measures are still to be taken that can result in the longevity, competitiveness and survival of *Trichoderma* on fields.

MATERIALS AND METHODS

Isolation and selection of strains

Trichoderma strains were isolated from the soil of pulse fields of various districts of Uttar Pradesh (India) and were tested against phythopathogens. The most promising isolates were selected for biochemical, molecular and disease suppressiveness tests. Initially, a total of 7 strains were identified and were selected for further study. Based on the descriptions of Bissett (1991), these fungi are classified as: *Trichoderma* anamorph and *Hypocrea* teleomorph. The isolates were screened for antagonistic activity towards the major soil borne fungi such as *Fusarium solani, Rhizoctonia solani, Pythium ultimum, Macrophomina phaseolina, Sclerotinia sclerotiorum, Phytophthora* and *Fusarium oxysporum* that were previously isolated and identified in the Bio-Control Laboratory, Department of Plant Pathology, CSAUAT, Kanpur (India).

In vitro bioassay

In vitro bioassay was conducted between the *Trichoderma* isolates and the phytopathogenic fungi in Petri dishes containing Malt agar (MA) (Difco). Isolates, which showed a marked effect towards pathogens were selected and used for further study. Each *Trichoderma* isolate was separately inoculated into 100 ml PDB and incubated at 20°C for 10 days. After incubation, the cultures were filtered through 0.22 mm millipore filters and the aliquots (2 ml) of these filtrates were placed in sterile Petri dishes and 25 ml of 1/4 strength PDA at 45°C was added. Once the agar solidified, mycelial discs of the pathogens (7 mm in diameter) obtained from actively growing colonies were placed gently on the centre of the agar plates. The Petri dishes were incubated at 20°C for 6 days. There were three replicates for each experiment and the growth reduction of the pathogens was recorded.

Morphological descriptors such as colony morphology, colony color, colony edge and others of each strain were studied.

Xylanase enzyme activity assay

Xylanase enzyme activity was assayed using 1% (w/v) birchwood xylan as a substrate. The reaction mixture contained 1ml of 1% xylan solution (in 0.1M, pH 5 sodium citrate buffer) and 2 ml of enzyme was added to the reaction tubes and incubated at 40°C. The amount of reducing sugar in the reaction tubes was measured using the DiNitrosalicylic Acid Method. After heating the tubes for 5 minutes in a water bath and then cooling, the absorbance was read at 550 nm using UV spectrophotometer. The amount of reducing sugar was calculated from the standard curve based on the equivalent xylose. One unit of xylanase activity is defined as 1 µmol of xylose equivalent produced/ min under the assay conditions.

Simple sequence repeats (SSR) analysis

DNA was extracted using cetyltrimethyl ammonium bromide (CTAB) method from all seven isolates and quantified using agarose gel electrophoresis. SSR primers were selected and polymerase hain reaction (PCR) was programmed with an initial denaturing for 4 min at 94°C; followed by 35 cycles of denaturation for 1 min at 94°C; annealing at 36°C for 1 min; extension for 90 s at 70°C, and a final extension for 7 min at 72°C in a Primus 96 advanced gradient Thermocycler. PCR product (20 µl) was mixed with loading buffer (8 µl) containing 0.25% Bromophenol Blue, 40% (w/v) sucrose in water and then loaded in 2% agarose gel with 0.1% ethidium bromide for examination by horizontal electrophoresis.

Electrophoresis

The amplification products were analyzed by electrophoresis according to Sambrook and Russell (2001) in 2% agarose in Tris-acetate-EDTA (TAE) buffer (for a litre of 50X TAE Stock solution, 242 g Tris Base, 57.1 ml Glacial Acetic Acid and 100 ml 0.5M EDTA was used), stained with 0.2 µg/ml ethidium bromide. Nucleic acid bands were photographed and detected by BioRad Gel Doc system.

Mass multiplication of *Trichoderma harzianum (Th.azad)* strain

Bajra (Pennisetum typhoides) grains should be completely soaked in 2% sucrose solution in water for 6 h. After draining out the excess water the soaked 250 g seeds of bajra should be filled in autoclavable poly-propylene (PP) bags of 30 × 20 cm^2. The PP bags should be plugged with nonabsorbent cotton followed by autoclaving at 15 lbs pressure for 30 min. After autoclaving, the bags should be left for cooling overnight. Next day the bags should be individually inoculated by using 5 ml stock solution (10^6 - 10^8 CFU/ml) of starter culture grown for 100 days, with syringe. Before inoculation, the place from where the inoculation is to be made should be marked out with a small circle with the help of marker pen. Punctured place of injection of the PP bag must be sealed with cellophane tape. The bags should be incubated at 25 ± 2°C for 15 days in a temperature controlled room. After 15 days of incubation, the contents of the bags should be taken out and kept in hot air oven for drying overnight at 35°C. During the 15 days of incubation visual check every day is essential to ensure detection and elimination of contaminated PP bag(s). Formulation thus prepared should be ground to fine powder, while ensuring that during the process temperature does not go beyond at 35°C. The powdered formulation thus obtained should be mixed with pre-sterilized talc in 1:9 (Trichoderma spore:talc) ratio. Three samples should be taken from each but lot during production and tested using a standardized method to determine the viability of the active ingredient expressed as colony forming units (CFU). The product thus prepared is ready for packaging at this stage. For storage the finished product should be stored in vacuum filled plastic bags, covered by paper cartons of different sizes (250, 500 and 1000 g). These packets should be

Table 1. Details of *Trichoderma* species.

Strain No.	Name of Bio-agent	Strain code	ITCC Acc. No	NBAIM Acc. No.	Gen bank NCBI No.	Source	GPS
T1	*T. viride*	01PP	8315	F-03110	JX119211	Hardoi (U.P., India)	Latitude: 27˚ 23′ 40.729″ Longitude: 80˚ 7′ 47.751″
T2	*T. harzianum*	*Th* azad	6796	F-03109	KC800922	CSA Kanpur Nagar(U.P., India)	Latitude: 25˚ 8′ 34.821″ Longitude: 81˚ 59′ 2.979″
T3	*T. asperellum*	Tasp/CSAU	8940	F-03108	KC800921	CSA Kanpur Nagar (U.P., India)	Latitude: 26˚ 29′ 33.384″ Longitude: 80˚ 18′ 6.518″
T4	*T. koningii*	T_K (CSAU)	5201	F-03112	KC800923	CSA Kanpur Nagar(U.P., India)	Latitude: 26˚ 29′ 33.384″ Longitude: 80˚ 18′ 6.518″
T5	*T. atroviride*	71 L	7445	F-03107	KC 008065	Hardoi (U.P., India)	Latitude: 26˚ 34′ 27.61″ Longitude: 79˚ 18′ 24.623″
T6	*T. longibrachiatum*	21 PP	7437	F-03111	JX978542	Kaushambi (U.P., India)	Latitude: 25˚ 21′ 39.794″ Longitude: 81˚ 24′ 11.414″
T7	*T. virens*	*T.vi* (CSAU)	4177	F-03106	KC800924	CSA Kanpur Nagar (U.P., India)	Latitude: 26˚ 29′ 28.323″ Longitude: 80˚ 18′ 26.361″

then kept in sealed cartons for transportation purpose (Figure 1).

RESULTS AND DISCUSSION

Isolation and bioassay

Seven isolates of *Trichoderma* sp. were isolated from the soils of pulse fields of various districts of Uttar Pradesh, India. These include *T. harzianum, Trichoderma viride*, *Trichoderma asperellum, Trichoderma koningii, Trichoderma atroviride*, *T. longibrachiatum* and *Trichoderma virens*. All tested strains of genus *Trichoderma* had high or moderate antagonistic activity towards pathogens expressed as a zone of inhibition and fungal growth reduction by using culture filtrate. It was also found that the most effective species were *T. harzianum* and *T. viride* against all test pathogens. Isolated *Trichoderma* strains were submitted to the Indian Type Culture Collection (ITCC) and GenBank (NCBI) database and accession numbers allotted to specific strain of each species (Table 1).

Morphological description

Morphological study of the *Trichoderma* strains have been done and the characters include various parameters such as colony growth rate, colony colour, colony edge, mycelial form, growth pattern and speed along with morphology of conidia and phialids, conidia colour, shape and size etc. were studied for the identification of each strain of the genus *Trichoderma* (Table 2).

Xylanase enzyme production

The growing importance of many *Trichoderma* strains as BCAs and producers of valuable metabolites and enzymes have made their distinction from other *Trichoderma* isolates

Table 2. Morphological descriptors used for the characterization of native isolates of *Trichoderma* spp.

Name of strains	Colony growth rate (cm/day)	Colony color	Reverse color	Colony edge	Mycelial form	Mycelial color	Conidiation	Conidiophore branching	Conidia wall	Conidial color	Chlamy-dospores
T. viride (01 PP)	8 - 9 in 3 days	Dirty green	Dark greenish	Smooth	Floccose to Arachnoid	Watery white	Ring like zones	Ball like structure	Rough	Green	Not observed
T. harzianum (*Th* Azad)	8 - 9 in 3 days	Dark green	Colorless	Wavy	Floccose to Arachnoid	Watery white	Ring like zones	Highly branched, regular	Smooth	Dark Green	Not observed
T. asperellum (*Tasp* /CSAU)	5 - 6 in 3 days	Snow white green	Orange	Smooth	Floccose	Watery White	Ring like zones	Branched, regular	Smooth	Green	Not observed
T. koningii (*Tk* (CSAU)	7 - 8 in 3 days	Dirty green	Yellowish	Smooth	Floccose to Arachnoid	Watery white	Ring like zones	Highly branched, regular	Rough	Grayish Green	Not observed
T. atroviride (71L)	5 - 6.5 in 3 days	Light dark effuse	Colorless	Effuse	Floccose to Arachnoid	Watery white	Irregular	Irregular	Rough	Yellowish Green	Not observed
T. longibrachiatum (21PP)	8 - 9 in 4 days	White to green	Colorless	Effuse	Floccose to Arachnoid	Watery white	Circular zones	Rarely re-branched	Smooth	Green	Not observed
T. virens (*Tvi* (CSAU)	8 - 9 in 3 days	Snow white	Colorless	Smooth	Floccose to Arachnoid	Watery White	Flat	Highly branched, regular	Smooth	Dirty Green	Not observed

essential. *Trichoderma*, being a saprophyte adapted to thrive in diverse situations, produces a wide array of enzymes. Strains of *Trichoderma* can produce extracellular enzymes and antifungal antibiotics that may act as competitors to fungal pathogens and induce resistance in plants. By selecting strains that produce a particular kind of enzyme, and culturing these in suspension, industrial quantities of enzymes can be produced.

Mycoparasitism involving lytic enzymes has been described as the mechanism of action of *Trichoderma* species in the biological control of commercially important plant pathogens. However, little information is available on the significance of this mechanism for the biological control of soil borne pathogens. Xylanase enzyme activity for all seven *Trichoderma* isolates on broth media containing different carbon sources is shown in Figure 1. Maximum activity of xylanase on media containing birchwood xylan was found in *T. harzianum* (*Th* Azad) followed by *T. viride* 01PP, *T. asperellum* (*Tasp*/ CSAU), *T. koningii* (*Tk*/(CSAU), *T. atroviride* (71 L), *T. longibrachiatum* (21PP) *and T. virens* (*Tvi* (CSAU) etc.

The objective of the study is to extract and characterize xylanases from *Trichoderma* sp. Isolated from environmental soil samples. The metabolic activity and enzyme productivity of fungi is influenced by environmental conditions such as pH, cultivation period and temperature, concentration and the nature of the substrate used. In this context, the aim is to analyze various factors that may increase the xylanase production in the fungus *Trichoderma* such as, initial pH of the growth environment, carbon source, cultivation period and concentration of substrate used in the growth environment.

For commercial realization and economic viability of xylanase production, it is necessary to identify organism which can hyper-produce the enzymes. Some physiological conditions like the

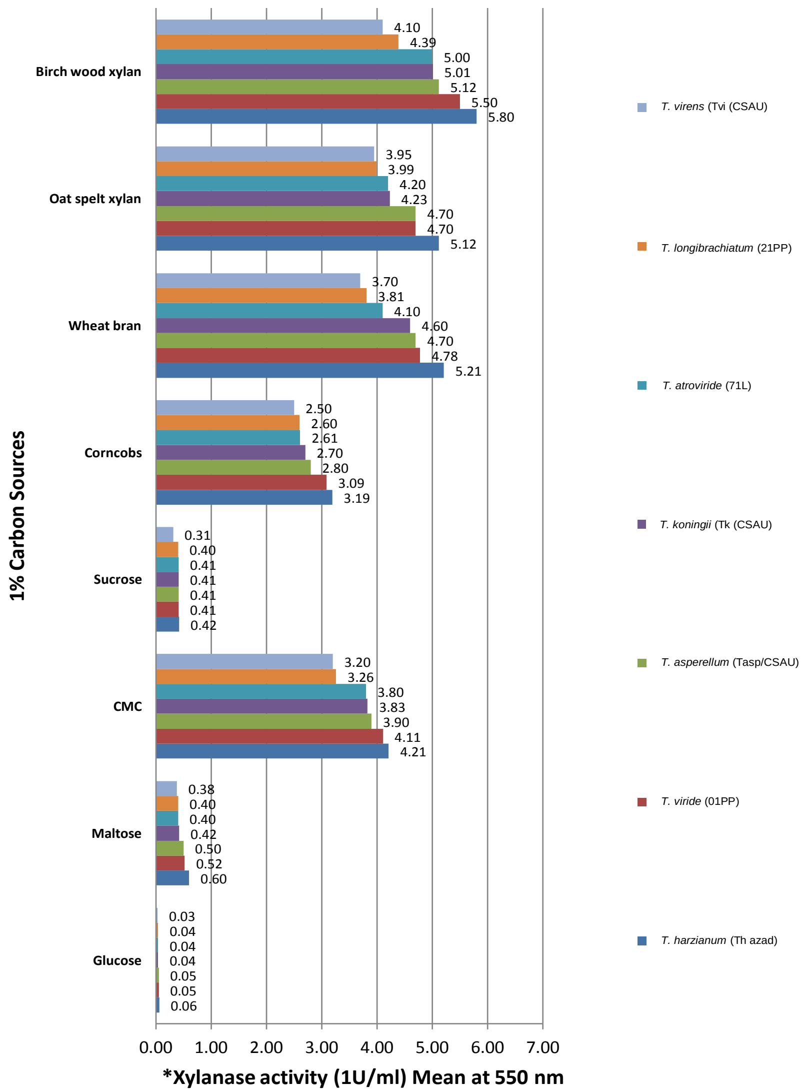

Figure 1. Xylanase activity produced by *Trichoderma spp.* grown on different carbon sources.

activity of xylanase enzyme produced from *Trichoderma* sp. by using different carbon sources, pH, temperature and substrate concentration were determined (Table 3).

Molecular characterization of Trichoderma sp. using SSR markers

Set of SSR primers were used. The preliminary studies indicates that *Trichoderma* isolates has very good diversity and there is a strong possibility to get the isolate-specific primers that will be utilized for identification of the particular *Trichoderma* isolates with a good biological potential from the field isolates without undergoing the cumbersome bioassay. All reproducible polymorphic bands were scored and analyzed following Unweighted pair-groups method using arithmetic averages (UPGMA) cluster analysis protocol and computed *in silico* into similarly matrix using NTSYSpc.

The size of the fragments (molecular weight in base pairs) was estimated by using 1 Kb ladder marker, which was run along with the amplified products. In the gel, “1” indicates the presence of a band whereas “0” indicates the absence of any band. Out of seven strains of *Trichoderma* sp. tested, the percentage of polymorphism in SSRs obtained was more than 77%. This shows that there is a complete variability within the strains of *Trichoderma* spp. being isolated from different fields. This would enable us to develop a potential strain possessing competitive ability, growth promoting characters and inducing resistance in plants.

Dendrogram shown in Figure 2 revealed that all the

Table 3. Properties of fungal xylanase.

Organism	Name of strains	Optimum pH	Optimum temperature (˚C)
T. viride	01PP	4.5	55 - 60
T. harzianum	*Th* Azad	5.0	45
T. asperellum	*Tasp* /CSAU	4.0 - 5.0	70
T. koningii	*Tk* (CSAU)	5.0	40
T. atroviride	71L	5.0	60
T. longibrachiatum	21PP	6.0	55
T. virens	*Tvi* (CSAU)	5-5.5	45

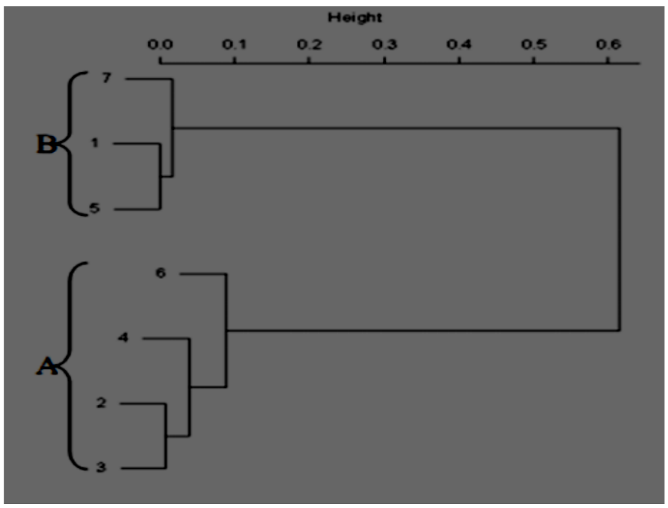

Figure 2. Dendrogram for *Trichoderma spp.* isolates as revealed by SSR markers; where: 1: *Th* Azad, 2: 71L, 3: 21PP, 4: *Tk* (CSAU), 5: *Tasp/*CSAU, 6: *Tvi* (CSAU), 7: 01PP.

seven isolates of *Trichoderma* sp. were distinctly divided into two major Clusters A and B at 20 units. Isolate *Tk*/CSAU and 01PP spanned the extremes of the entire dendrogram. Genetic dissimilarity ranged from a lowest value of 0.143 to a highest value of 0.857 (between *Tasp*/CSAU and *Tk* (CSAU). Isolates *Tk* (CSAU), 71L, 21PP, and *Tvi* (CSAU) were assigned to Cluster 'A'. Genetic dissimilarity among the entries in this cluster ranged from a lowest of 14.3% (between 21PP and *Tvi* (CSAU) to a highest of 35.7% (between *Tvi* (CSAU) and *Tk* (CSAU). The other Cluster 'B' comprised of three isolates namely *Th* Azad, *Tasp* (CSAU) and 01PP were grouped together. The genetic dissimilarity in this group ranged from 33.3% between *Tasp* (CSAU) and 01PP to 75% between *Th* Azad and 01PP (Table 4).

Bioformulation and its validation under *in vitro* conditions

Talc-based bioformulation of *Trichoderma* is prepared as it is relatively cheap and easily accessible to farmers for use on fields. It can be stored in plastic bags for long as it has been observed that storing the talc-based bioformulation in plastic bags increases the shelf-life of *Trichoderma* preserving its bio-efficacy simultaneously.

Shelf life of *Trichoderma* in talc as a carrier material was determined at a time interval of 30 days that further indicated that the number of propagules started declining from 30th day onwards. Talc-based bioformulation was found to be the best material to retain maximum number of viable propagules. That is, 29.7 × 10^6 CFU/g at 180 days of storage. It has also been found that the isolates can retain their viability up to 120 days in all the cases (Figure 4).

The commercial use of *Trichoderma* BCAs must be preceded by precise identification, adequate formulation, and studies about the synergistic effects of their mechanisms of biocontrol. *T. harzianum* (*Th* Azad) have been reported as the most important BCAs against plant pathogenic fungi. The strain distribution in several genotypes could also support the idea of developing

Table 4. A matrix displaying the genetic distances between the seven isolates of *Trichoderma* sp.

Strain	*Th* Azad	71L	21PP	*Tk*/CSAU	*Tasp*/CSAU	*Tvi* (CSAU)	01PP
Th Azad	0						
71L	0.544	0					
21PP	0.643	0.231	0				
Tk/CSAU	0.544	0.333	0.231	0			
Tasp/CSAU	0.667	0.769	0.643	0.857	0		
Tvi (CSAU)	0.643	0.231	0.143	0.357	0.643	0	
01PP	0.750	0.643	0.533	0.733	0.333	0.533	0

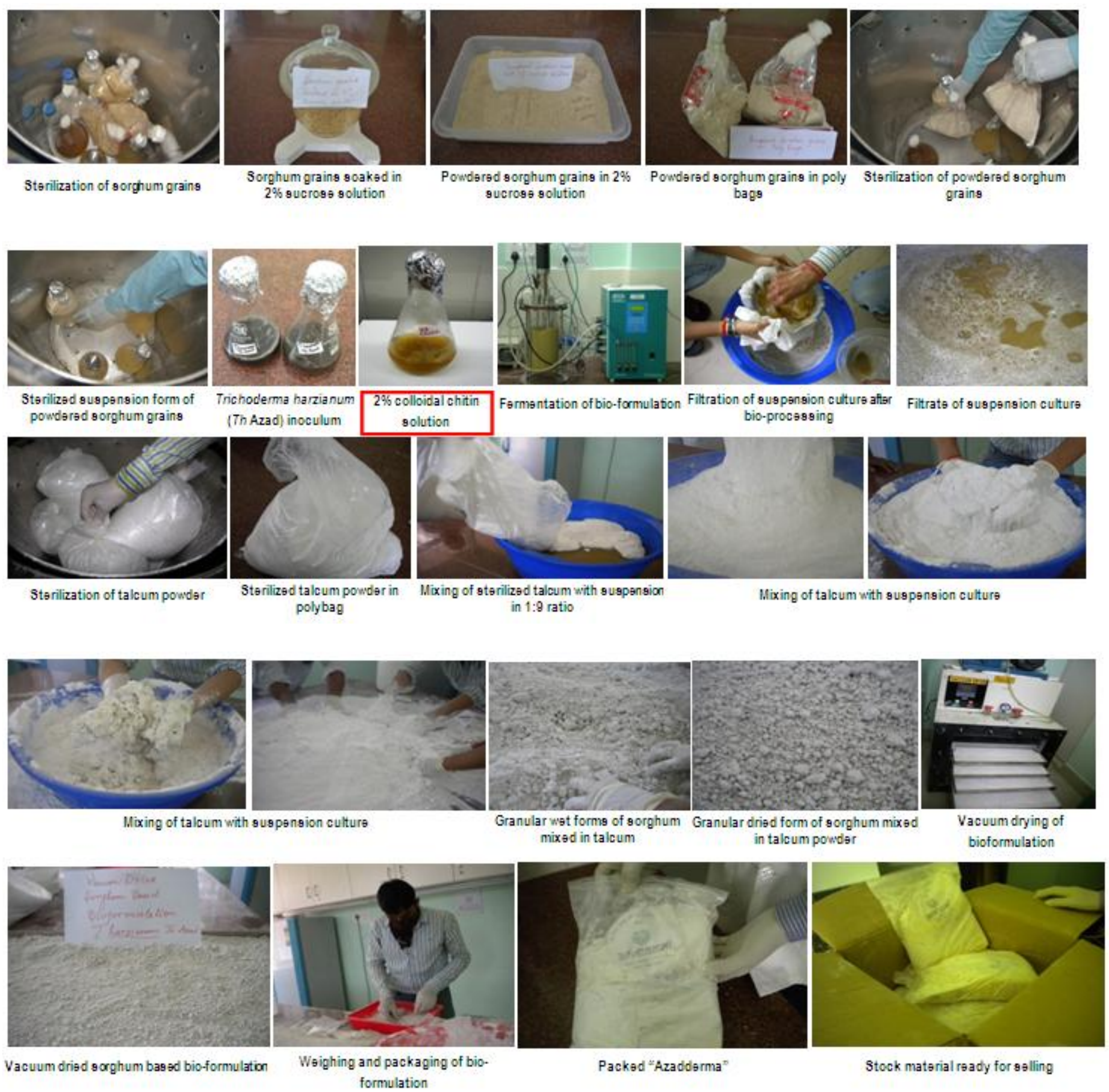

Figure 3. Production steps of *Trichoderma harzianum* (Th Azad) bioformulation.

antifungal formulations in which different *Trichoderma* BCAs could be combined. The use of *Trichoderma*-based products is not only safe for the farmers and consumers but it also proves friendly to the environment.

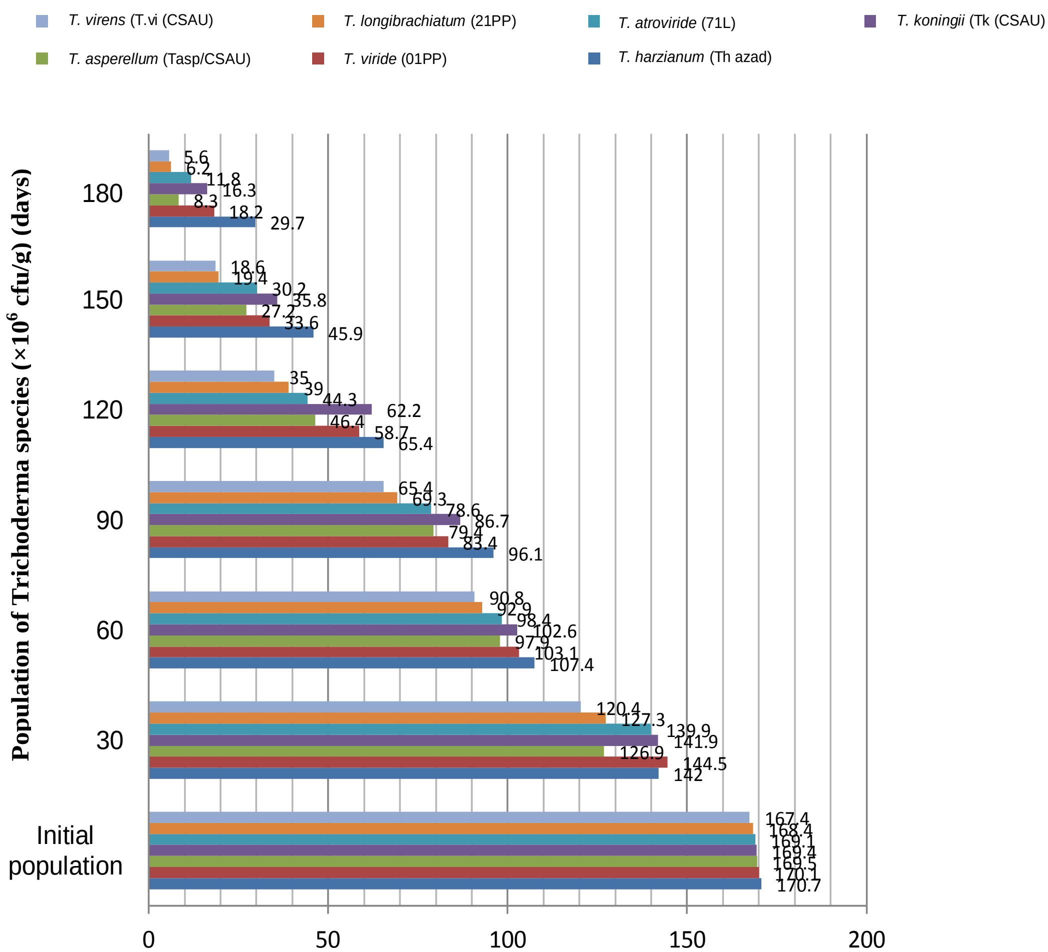

Figure 4. Effect of Talc as a carrier on the population of *Trichoderma* spp.

Table 5. Effect of bioagent *Trichoderma harzianum* (*Th* Azad) on seed germination, root and shoot length and seedling vigour in chickpea (Paper Towel Method).

Parameter	Treated Seeds	Control
Seed Germination	87.66%	80.56%
Root Length	9.7 cm	8.8 cm
Shoot Length	5.2 cm	4.9 cm
Vigour Index*	1306.13	1103.67

Note: The data on the percent seed germination, root and shoot length and seedling vigour index recorded after seven and ten days of sowing, respectively.

The efficacy of bioformulation was ascertained on the seed germination and seedling vigour under laboratory conditions by using paper towel method. It was found that seed treatment with the bioformulation *T. harzianum* (*Th* Azad) (5 g/kg seeds) was able to increase the seed germination, root and shoot length and seedling vigour over untreated ones (Table 5).

Validation of the bioformulation under in vitro conditions

Under natural conditions, application of talc-based solid formulation of *Trichoderma* in soil provides protection against wilt disease in leguminous crops. Higher reduction in wilt was obtained in lentil and pigeonpea crops. As compared with the control and other strains, application of *T. harzianum* (*Th* Azad) was more effective in reducing the wilt disease caused by *Fusarium. Trichoderma* species can act as biocontrol agents through different synergistic mechanisms. However, it is difficult to predict the degree of synergism and the behavior of a BCA in natural system. Considering that the environmental conditions are important, the right selection of BCAs, which begins with a safe characterization of biocontrol strains in the new taxonomic schemes of *Trichoderma*, is equally important since the exact identification of strains at the species level is the first step in utilizing the full potential of fungi in specific applications. *Trichoderma* species play an important role in controlling fungal plant pathogens, especially soil borne fungal pathogens. Strains of *Trichoderma* can produce extracellular enzymes and antifungal antibiotics, they may also be competitors to fungal pathogens, promote plant growth, and induce resistance in plants.

The commercial use of *Trichoderma* BCAs must be preceded by precise identification, adequate formulation, and studies about the synergistic effects of their mechanisms of biocontrol. *T. harzianum* Rifai have been reported as the most important BCAs against plant pathogenic fungi. The strain distribution in several genotypes could also support the idea of developing antifungal formulations in which different *Trichoderma* BCAs could be combined. The use of *Trichoderma*-based products is not only safe for the farmers and consumers but it also proves friendly to the environment.

Conclusion

It is concluded from the study that *Trichoderma* sp. has been successfully isolated, identified, characterized and used as an effective biocontrol agent against wilt caused by other pathogenic fungi. Seven strains of *Trichoderma* isolated from wilt infected leguminous crops tested in the laboratory for the identification of pathogens infecting the crops. Strains have been examined morphologically and at molecular level as well. Specific markers have been defined that could quickly identify specific strains and amplify them. Genetic variability among the strains studied with the help of a set of SSR markers. The effect of enzyme activities during interaction with the pathogen is also counted and the data reveals the best carbon source for the enzyme for its induction. In the end, a talc based bioformulation is prepared that showed beneficial effects when applied on wilt infected crops on pulse fields.

Conflict of Interests

The author(s) have not declared any conflict of interests.

ACKNOWLEDGEMENT

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Abbreviations: PDA, Potato dextrose agar; **PDB,** potato dextrose broth; **EDTA,** ethylene diamine tetra-acetic acid; **w/v,** weight/volume; **CTAB,** cetyl trimethyl ammonium bromide; **PCR,** polymerase chain reaction; **SSR,** simple sequence repeats; **TAE,** tris base, acetic acid and EDTA; **CMC,** carboxy methyl cellulose; **CSAU,** Chandra Shekhar Azad Agriculture University; **BCA,** biological control agent; **RFLP,** restriction fragment length polymorphism; **ITCC,** Indian Type Culture Collection; **NCBI,** National Centre for Biotechnology Information; **ITS,** internal transcribed spacer.

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Genetic variability in the isolates of *Bipolaris maydis* causing maydis leaf blight of maize

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Thirteen isolates of *Biploaris maydis* (BM 1- BM13) were collected from different locations of India and their genetic variability was studied using random amplified polymorphic DNA (RAPD), internal transcribed spacer (ITS) and internal transcribed spacer-restriction fragment length polymorphism (ITS-RFLP) techniques. Of the 31 RAPD primers, 21 primers showed polymorphisms in the isolates, but 10 primers failed to exhibit any polymorphic bands. Number of amplified products obtained was specific to each primer ranging from 5 bands (primer 4, A-01) to 21 (primer 7, A-04) and also all primers showed 100% polymorphism with fragment size varying from 200 bp to 3 Kb. Unweighted pair group method using arithmetic averages (UPGMA) analysis revealed one major cluster excluding the isolates BM1, BM5, and BM12. Jashipur isolate BM12 was outlier and showed minimum similarity of 48% with other isolates. The major cluster was further sub-clustered into two. Maximum closeness (92%) was observed between BM4 and BM11 collected from Ludhiana and Barapani, respectively which were 91% similar with BM7 of Jorhat. PCR-amplified ITS segments exhibited a single band of approximately 596 bp from all the thirteen isolates corresponding to primer pair *ITS1/ITS4*. PCR-RFLP analysis carried out with *Hae*III, *Rsa*I, *Hind* III, *Eco*RI, *Alu*I, *Basp*1431 and *Taq*I produced two detectable fragments of about 220 and 380 bp uniformly from the test isolates of *B. maydis* without detecting any genetic variations.

Key words: *Bipolaris maydis*, Indian isolates, maize, variability, random amplified polymorphic DNA (RAPD), internal transcribed spacer-polymerase chain reaction (ITS-PCR), internal transcribed spacer-restriction fragment length polymorphism (ITS-RFLP).

INTRODUCTION

Maize or corn (*Zea mays* L.), is regarded as the queen of cereals due to its high yield efficiency. Maize is the third most important food grain in India next to wheat and rice. Despite its high yield potential, one of the major limiting factor of maize grain yields is its sensitivity to several biotic stresses especially the diseases. About 65 pathogens infect maize (Rahul and Singh, 2002) and of these, maydis leaf blight (MLB) or southern corn leaf blight (SCLB) is considered as one of the serious diseases. The extent and severity of MLB disease varies from season to season. In warm (20-32°C) and moderately humid environment of the world, maydis blight is potentially damaging and may cause significant yield losses (Bekele and Sumner, 1983; Thompson and

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Table 1. Isolates of *Bipolaris maydis* collected from different regions of India.

S/N	Isolate name	Code	Host	Place
1	*B. maydis*	BM1	*Zea mays*	Kalimpong, West Bengal
2	*B. maydis*	BM2	*Zea mays*	Ludhiana, Punjab
3	*B. maydis*	BM3	*Zea mays*	Dhaulakuan, Himachal Pradesh
4	*B. maydis*	BM4	*Zea mays*	Ludhiana, Punjab
5	*B. maydis*	BM5	*Zea mays*	Gossaigaon, Assam
6	*B. maydis*	BM6	*Zea mays*	Changla, Himachal Pradesh
7	*B. maydis*	BM7	*Zea mays*	Jorhat, Assam
8	*B. maydis*	BM8	*Zea mays*	Udaipur, Rajasthan
9	*B. maydis*	BM9	*Zea mays*	Nahan, Himachal Pradesh
10	*B. maydis*	BM10	*Zea mays*	Ludhiana, Punjab
11	*B. maydis*	BM11	*Zea mays*	Barapani, Meghalaya
12	*B. maydis*	BM12	*Zea mays*	Jashipur, Odisha
13	*B. maydis*	BM13	*Zea mays*	Delhi

Bergquest, 1984). Most commonly two physiological races, T and O of *Bipolaris maydis* (syn. *Helminthosporium maydis*, Telomorph: *Cochlibolus heterostrophus*) are responsible to cause leaf blight disease in maize (Smith et al., 1970). Lesions produce by T strain are oval and larger than those produced by the O strain. A major difference is that the T strain affects husks and leaf sheaths, while the O strain normally does not. Race O, is still a significant problem in the southern Atlantic coast area of the United States and parts of India, Africa, and Western Europe where it can cause grain yield losses of 40% or more (Byrnes et al., 1989; Gregory et al., 1979).

In recent years, a great deal of interest has been generated in the study of variability using molecular tools, which make the quantification of genetic variation in a relatively straight forward endeavour (Brown, 1996; Michelmore and Hulbert, 1987). Molecular tools provide exciting avenues for identification of pathogen and host genes. The use of DNA profiling systems reveals variation in nucleotide sequence of DNA. A number of molecular marker system have been developed and utilized for characterization of plant pathogens. All these marker system are based on two techniques (i) Southern blotting (ii) Polymerase Chain Reaction (PCR) developed by Southern (1975) and Mullis et al. (1986), respectively. The PCR is simple and has revolutionized the development of molecular markers. The method known as RAPD (Random amplified polymorphic DNA) is also another simple technique which is faster than other DNA fingerprinting techniques. It uses a single oligonucleotide primer in a PCR (Polymerase chain reaction) with low stringency. The technique requires no sequence information prior to analysis, but needs only a minute amount of DNA (Welsh and McClelland, 1990; Williams et al., 1990). Thus, the molecular markers are highly polymorphic nature, show co-dominant inheritance, occur frequently in genome, unbiased to environmental condition or management practices and easily available, highly reproducible and allow easy exchange of data between laboratories (Shrivastva and Mishra, 2009). So far, the genetic nature or race profile of the Indian isolates of *B. maydis* has not been determined although it has been reported as the race O based on the morphological features, growth characteristics and pathogenic behaviour. Considering all these facts, a study was carried out to determine the genotypic variations among the isolates of *B. maydis* collected from different geographical locations of India by employing the molecular appliances.

MATERIALS AND METHODS

Collection of diseased specimen and pathogen isolation

Diseased leaves of MLB were collected from different maize growing ecosystems of India (Table 1). Infected leaves were thoroughly washed in clean water. Disc of 1 to 2 mm infected leaf tissue with advanced lesions was cut using a sterilized blade and surface sterilized using 1% sodium hypo-chloride. The sterilized leaf discs were then transferred aseptically into Petri plates containing potato dextrose agar (PDA) medium and the plates were incubated at ±25°C for 3 to 5 days. After the growth of pathogen, pure cultures were made by hyphal tip method. The cultures were maintained on PDA slants in refrigerator for further use.

Isolation of genomic DNA from *B. maydis*

Potato dextrose broth (PDB) was used for mycelial growth of *B. maydis* for extraction of DNA. One hundred and fifty millitre of medium was dispended in 500 ml conical flask and sterilized at 121.6°C at 15 lb (6.8 kg) for 20 min. Each flask was inoculated with 10 mm mycelial disk of the fungus taken from the actively growing pure cultures of the isolates on PDA plate. The inoculated flasks were inoculated for 7 days at 28 ± 2°C in shaker incubator (Kuhner ISF-I-V, Switzerland). After incubation, the mycelial mats were harvested by filtering through sterilized Whatman paper No. 1, washed with sterile distilled water and air dried.

Nucleic acid extraction

The genomic DNA was isolated according to the protocol given by Reader and Broda (1985) with slight modification. First mycelium was crushed in pre-chilled mortar-pestle using liquid nitrogen and sample was transferred into 2 ml appendorf tube and 1 ml of extraction buffer was added to it. These were mixed well and incubate at temperature 65°C for 60 min. After incubation, the mixture was cooled at room temperature. Thereafter, equal volume of mixture of Chloroform: Isoamyl-alcohol (24:1) was added. The mixture was centrifuged at 13000 rpm for 20 min at room temperature. After centrifugation, the aqueous phase was transferred to a fresh tube and then DNA was precipitated by adding 0.7 to 0.9% ice-cold Isopropanol. Now mixture was incubated at -20°C for 60 min or 4°C for overnight. The mixture was centrifuged at 10,000 rpm for 15 min at 4°C and supernatant was decanted carefully. The pellet was washed with 70% ethanol and dried at room temperature. Finally, the DNA pellet was dissolved in de-ionized, RNAse, DNase free TE.

Qualitative and quantitative analysis of *B. maydis* genomic DNA

The quality of DNA was measured using Nano Drop UV-Spectrophotometer (ND-1000) at 260 nm using TE buffer as a blank. The purity of DNA was determined by calculating the ratio of absorbance at 260 nm to that of 280 nm. 1.0 µl of this solution was put in the vial of nano-drop spectrophotometer and the absorbance of various samples was obtained. The absorbance ratio 260:280 should be 1.8 for pure DNA. Deviation from these ratios indicates contamination of protein and RNA.

Internal transcribed spacer-polymerase chain reaction (ITS-PCR)

The region of rDNA repeat from 3’ end of the 18S and 5’ end of the 28S gene were amplified using PCR condition with two primers (Table 2) which were synthesized on the basis of conserved region of the eukaryotic rRNA gene (White et al., 1990). For each primer (BIOLINK) a stock solution at concentration of 1 µg/µl was made in 1X TE. From this working dilution of 200 ng/µl was prepared for further use. The PCR amplification reaction were performed in a 25 µl mixture containing 50 mM KCl, 20 mM Tris HCl (pH 8.4), 1.5 mM $MgCl_2$, 200 mM of each of the four dNTPs, 30 pmol of each primer, 100 ng of template and 3 unit of Taq polymerase. The cycle parameter were included and initial denaturation at (94°C for 2 min), followed by 35 cycles consisting of denaturing at 94°C for 1 min, annealing at 55°C for 1 min and extension at 72°Cfor 1 min, and the final extension for 1 min at 72°C.

Random amplified polymorphic DNA analysis

RAPD condition for *B. maydis* isolates in the present investigation at which amplification assay was performed had the following conditions: Crude template DNA (~1 µl), 1.5 µl of 25 mM $MgCl_2$, 0.5 µl of 10 mM dNTP. 1 µl of primer, 2.5 units of Taq DNA polymerase (0.5 µl), 2.5 µl of 10X PCR buffer in reaction volume of 25 µl. For enhancement PCR amplification, organic compounds, viz. BSA (400 ng/µl) and DMSO (5%) were used. The standardized temperature profile of 94°C for 2 min followed by 35 cycles of 94°C for 1 min, 37°C for 1 min with an elongation of 72°C for 2 min with final extension of 72°C for 5 min which gave the best results was used in PCR.

Internal transcribed spacer-restriction fragment length polymorphism (ITS-RFLP)

The PCR products were digested using seven enzymes, *Rsa* I, *Alu* I, *EcoR* I, *Hae* III, *Hind* III, *Taq* I and *Basp*1431 according to the method given by Irene et al. (2004) with slight modification. Each digest reaction consisted of 2.5 µl RE 10X buffer with BSA, 11.5 µl water, 10 µl direct PCR product, and 1.0 µl restriction Enzyme. The digestion mixture was incubated at 37°C except *Taq* I (at 65°C) in water bath for 3 h or longer depending on the enzyme. The products of ITS, RAPD and ITS-RFLP were visualized in 2.0% agarose gels in 1X TAE, stained with ethidium bromide.

Data analysis

The RAPD pattern of each isolate was evaluated. Each amplification product was considered as RAPD marker and recorded across all samples by assigning binary values. The bands that could be reproduced in the gel were denoted with the value 1 and absence of band at same locus was assigned the value 0 (zero). Data was entered using a matrix in which all observed bands or characters were listed.

For pair wise comparison, the generated data matrix was used to calculate Jaccard’s similarity coefficient. The coefficients were calculated *in silico* following Jaccard (1908), using the formula: a / (n-d). Where, ‘a’ is the number of positive matches, d is the number of negative matches and ‘n’ is the total sample size including both the numbers of “match” and “unmatch”. NTSYS-pc version 2.0 software (Rohlf, 1990) was used to calculate the coefficients.

Cluster analysis

It was done using commonly adopted clustering algorithm in genetic diversity analysis, namely unweighted pair group method using arithmetic averages (UPGMA) (Crisci and Lopez Armengol, 1983; Rolhf, 1990) where similarity/dissimilarity (distance) between isolates in a cluster is established. After fusion of two most similar isolates, clustering continues between two next closest isolates or between any unplaced isolate and the established cluster. An unplaced isolate can join a cluster if its average similarity to all member of the cluster is small enough in comparison with any other pair of unplaced isolates. This process is repeated until all cluster join one cluster. This is an unweighted method because it gives equal weightage to each isolate within a cluster. The results of clustering were plotted in the form of dendograms.

RESULTS AND DISCUSSION

The RAPD profiles (bands) that were reproducible in two to three reactions were scored as 0 (fragment absent) and 1 (fragment present) in a data matrix and then, distance values were subjected to Jaccard’s similarity coefficient analysis using the software package NTSYS-PC version 2.0. Similarities were calculated by the simple matching method, Out of 31 primers screened for RAPD amplification of DNA of all the mentioned 13 isolates of *B. maydis* 10 resulted in either suboptimal or non-distinct amplification products, that is, they failed to give resolutions of amplified products. Therefore, these were discarded and remaining 21 primers were used for PCR amplifications (Table 2).

Hence, the final numerical analysis included the results

Table 2. List of ITS and RAPD Primers used for amplification of *B. maydis* isolates.

S/N	ITS Sequence	Primers
1	5'-TCC GTA GGT GAA CCT GCG G-3'	ITS 1
2	5'-TCC TCC GCT TAT TGA TAT GC-3'	ITS 4
	RAPD Sequence	
1	5'-CCA CAG CAC G-3'	P-14
2	5'-ATG GAT CCG C-3'	R-28
3	5'-GAT AAC GCA C-3'	RC-09
4	5'-TGC ACT ACA ACA-3'	A-01
5	5'-GGC AT G GCC TTT-3'	*A-02
6	5'-CGA CGACGA CGA-3'	A-03
7	5'-ATC AGC GCA CCA-3'	A-04
8	5'-AGC AGC GGC TCA-3'	A-05
9	5'-GCC AGC TGT ACG-3'	A-06
10	5'-TGC CTC GCA CCA-3'	A-07
11	5'-GCC CCG TTA GCA-3'	A-08
12	5'-CCG CAG TTA GAT -3'	*A-09
13	5'-ACT GGC CGA GGG-3'	A-10
14	5'-GAT GGA TTT GGG-3'	*A-11
15	5'-TTC GGA CGA ATA-3'	*A-12
16	5'-GTA GGC GTC G-3'	12ES10G-23
17	5'-GGC TCG TAC C-3'	13ES10C-24
18	5'-GAC CCC GGC A-3'	*14ES10A-25
19	5'-CAG GGA CGA-3'	15ES10A-26
20	5'-CGA CAC GTT C-3'	16ES10A-27
21	5'-AAT CGG GCT G-3'	*OPA-04
22	5'-GAA ACG GGT G-3'	*OPA-07
23	5'-GTG ATC GCA G-3'	CPA-10
24	5'-CAG CAC CCA C-3'	OPA-13
25	5'-AGG TAG CCG T-3'	OPA-18
26	5'-AAA GCT GCG G-3'	*OPC-11
27	5'-TAG GTG GGT C-3'	*OPC-18
28	5'-GTT GCC AGC C-3'	OPC-19
29	5'-AAG ACC CCT C-3'	*OPE-06
30	5'-TGC TGC AGG T-3'	OPF-14
31	5'-GTG ACGTCA C-3'	OPG-09

* Primers failed to amplify the genomic DNA.

from only 21 primer amplifications. Number of amplification products obtained was specific to each primer and ranged from 5 (primer 4, A-01) to 21 (primer 7, A-04, Figure 1) and also almost all primers showed 100% polymorphism with fragment size varying from 200 bp to 3 Kb. Out of 285 amplification products, 284 amplicons (99.64%) were polymorphic in nature. A high degree of polymorphism, in general, was obtained with most of the primers. At intra specific level a wide range of diversity existed Jaccard's similarity coefficients values of this index ranged from 0.48 to 0.92 (Figure 2), again indicating the presence of wide range of genetic diversity among the used isolates. The most diverse pair showing 48% similarity comprised of *B. maydis* isolate from Jashipur (BM12), whereas maximum closeness (92%) was observed between BM4 and BM11 collected from Ludhiana and Barapani, respectively.

The dendogram obtained after cluster analysis also exhibited variable degree of relationships among the isolates (Figure 2). There were one major cluster including all isolates except BM1, BM5 and BM12. BM12 was clearly outlier and showed minimum similarity of 48% with all isolates followed by BM5 and BM1 that showed 50 and 53% similarity, respectively with all the isolates in the cluster. The major cluster was further sub-clustered into two. The first sub-cluster included BM3, BM9 and BM13, in this BM3 and BM9 showed maximum similarity of 86% and both of them showed 85% similarity with

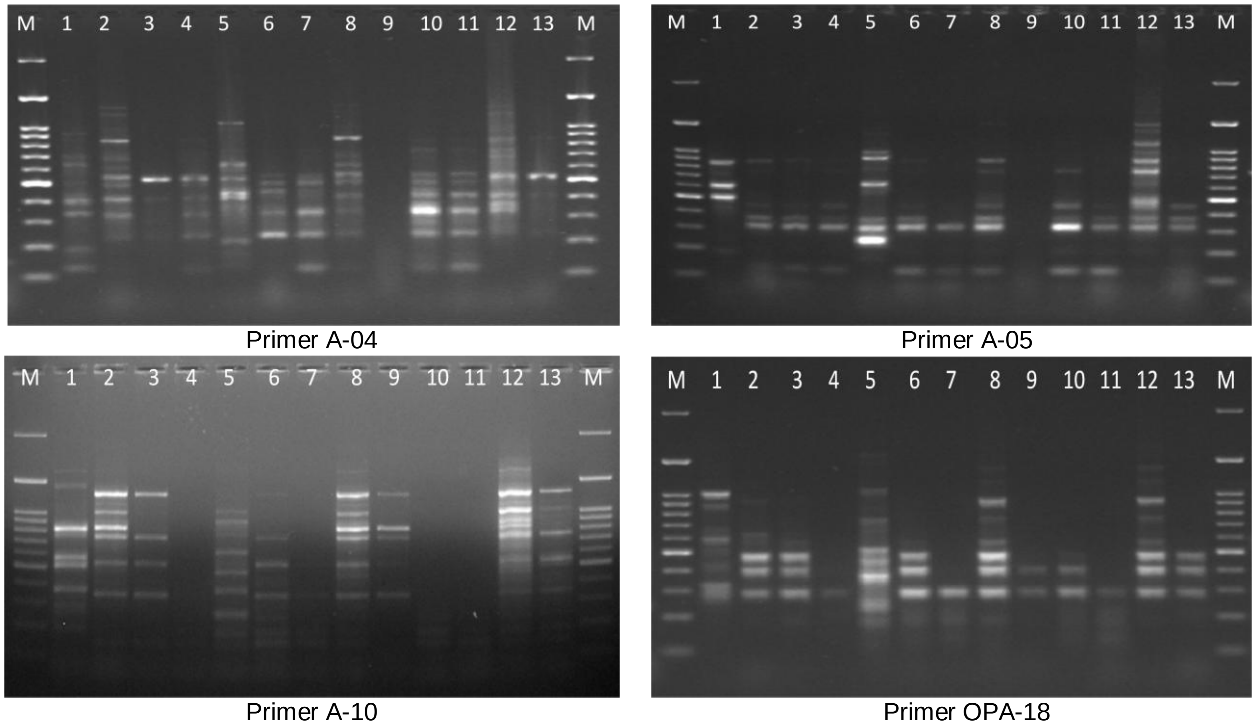

Figure 1. RAPD profile of 13 isolates of *Bipolaris maydis* developed by four primers A-04, A-05, A-10 and OPA-18 in agarose gel (1.5%). Lane 1 to 13: isolates BM1 to BM13, M= 100 bp ladder.

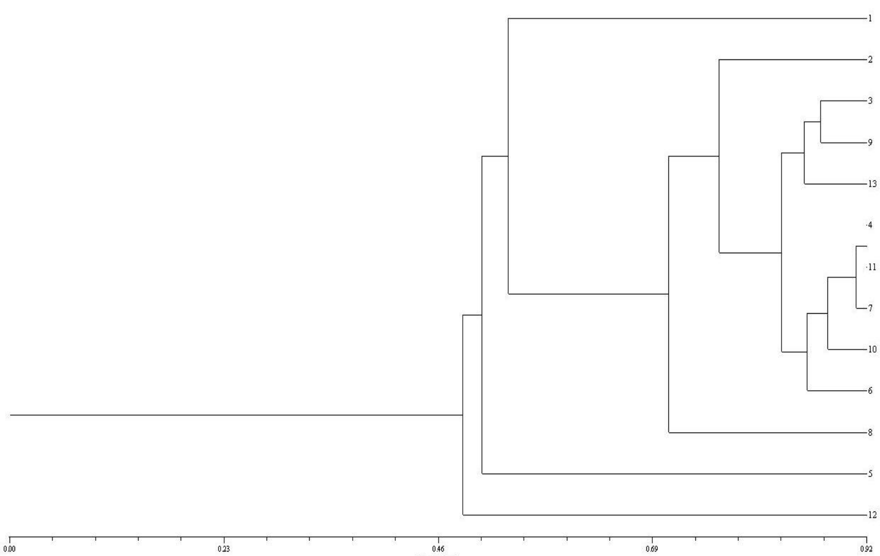

Figure 2. Phylogenetic relationship of thirteen isolates of *Bipolaris maydis* based on RAPD analysis.

BM13. Second sub-cluster included BM4, BM7 and BM11, where BM4 showed maximum (92%) similarity with BM11. But they (BM4 and BM11) were 91% similar with BM7. The isolates of *B. maydis* of the two sub-clusters exhibited 82% similarity. The isolates of these two sub-clusters were found to be 76% similar with BM2 and 70% similar with BM8. The dendogram showed that BM1, BM5 and BM12 are approximately 50% different from rest of the ten isolates as they were separated out from the major cluster.

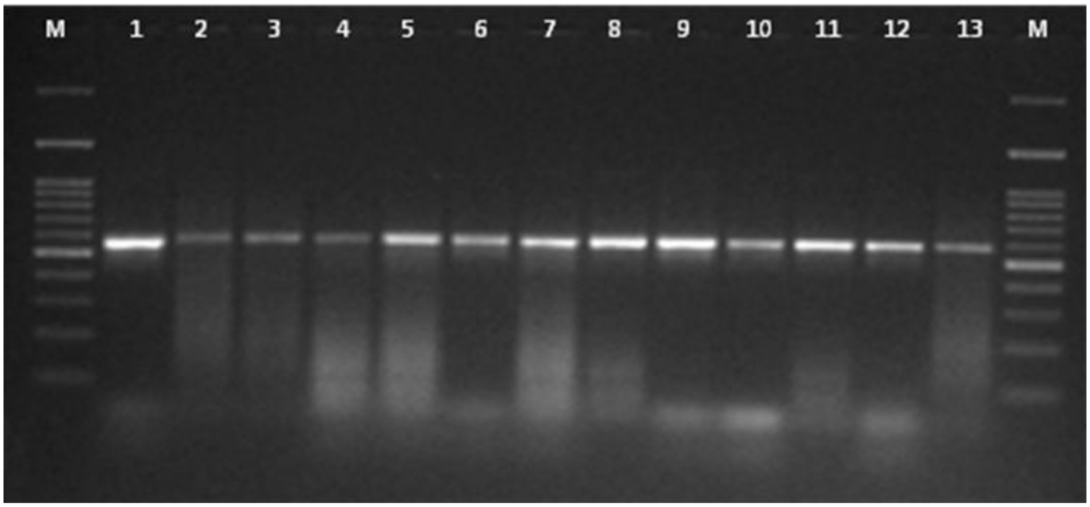

Figure 3. ITS profile of 13 isolates of *Bipolaris maydis* with ITS1 and ITS4. Lane 1 to 13: isolates BM1 to BM13, M= 100 bp ladder.

The clusters of RAPD dendogram revealed that there was no direct role of geographic variations to provide the distinct identity of the isolates of *B. maydis,* because the largest/major cluster included most of the isolates leaving aside three isolates viz. BM1, BM5 and BM12. The observed deviation could be due to migration of the pathogen through air from one location to another or through the seeds. The seed borne nature of *B. maydis* in maize seeds was reported by Kumar and Aggarwal (1998). Similar observations on migration of pathogen were made by Gopi (2008) where he found that all isolates of *B. maydis*, except Delhi isolate, formed a big cluster. Karimi (2003) also reported that there is a great deal of variation among the different *B. maydis* isolates collected from different geographical regions with respect to molecular variability evidenced by RAPD analysis. Jahani et al. (2008) found 89.2% similarity among the isolates of *B. maydis* which is in conformity with our results showing 82% similarity among the isolates BM3, BM4, BM6, BM7, BM9, BM10, BM11 and BM13 by forming two sub-clusters.

Gel electrophoresis of the PCR-amplified ITS segments each of the 13 isolates exhibited a single band of approximately 596 bp corresponding to primer pair *ITS1/ITS4* (Figure 3). No secondary bands were obtained other than the specific product. There was no clear length polymorphism of the ITS-PCR products was evident amongst isolates. The primers exhibited excellent specificity for amplification of the target genes by directing a product of the anticipated size. However, as expected, the ITS-PCR amplification was unable to exhibit genetic variations within the isolates of *B. maydis*. Henceforth, ITS-RFLP was carried out so as the find out if any variations existed among the isolates of *B. maydis* in ITS regions. Restriction enzymes *Pvu*I, BamHI and *Pst*I employed following the PCR reactions did not seem to cleave the ITS product. No digested products of the three restriction endonucleases could be observed. On the other hand, digestion with *Hae*III, RsaI, *Hind* III, *Eco*RI, *Alu*I, *Basp*1431 and *Taq*I produced two detectable fragments of about 220 and 380 bp from all the tested isolates (Figure 4) which also failed to detect polymorphisms (data not shown).

The present PCR-RFLP analysis also did not detect genetic variations in the isolates of *C. heterostrophus* (*B. maydis*). Although, the relatively small size of the PCR product and restriction enzymes employed may have also contributed to the result, the absence of polymorphisms could have been due to the fact the fungal isolates tested constitute similar rDNA genes. Gafur et al. (2003) performed PCR-RFLP to detect genetic variation in *B. maydis* using three restriction enzymes, *Hae*III, *Hha*I, and *Rsa*I, respectively, but they also could not reveal intraspecific variations within the fungus. Shi et al. (2010) used ITS-RFLP to distinguish *Erysiphe pulchra* and *Phyllactinia guttata*. The restriction enzyme *Alu*1 produced three fragments from *E. pulchra,* but could not digest *P. guttata.* In contrast, *Rsa I* yielded two DNA fragments from *P. guttata* but failed to yield any fragments from *E. pulchra*. However, they concluded PCR-RFLP as a very good tool to distinguish two pathogens *E. pulchra* and *P. guttata* provided some specific restriction enzymes are identified. Indeed, the PCR-RFLP approach has been developed and used as new tools for detection, identification, and phylogenetic studies of different fungal species (Nakamura et al., 1998).

To conclude, existence of genotypic variation was attempted to find out among Indian isolates of *B. maydis* by the analyses of RAPD, ITS and ITS-RFLP profiles. Although, RAPD showed polymorphisms among the thirteen isolates of the pathogen, but the products of ITS-

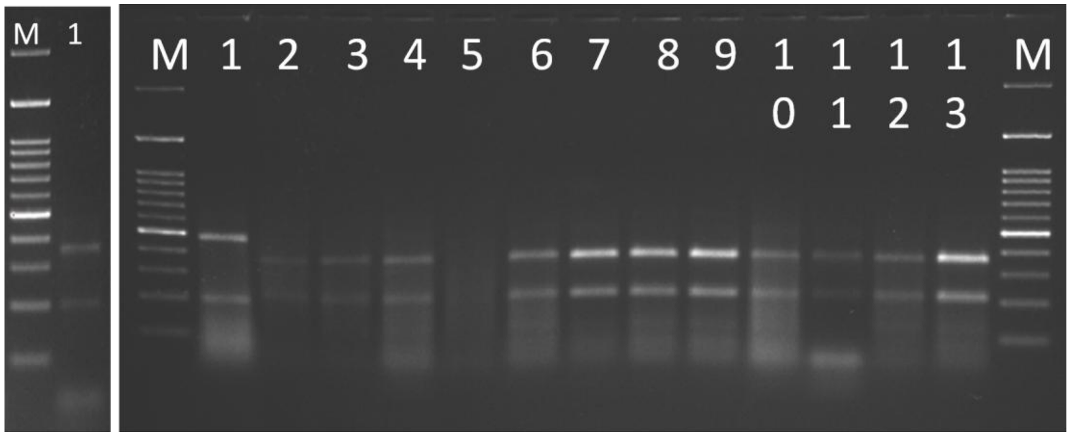

Figure 4. RFLP profile of 13 isolates of *Bipolaris maydis* with *Alu*I. Lane 1 to 13: isolates BM1 to BM13, M = 100 bp ladder.

PCR and PCR-RFLP analysis did not detect clear cut genetic variations in the isolates of *B. maydis* despite of their wide range of sources with greater geographical differences such as temperate climatic zone of Changla (Himachal Pradesh), dry zone of Jashipur (Odisha) and sub-tropical areas like Jorhat (Assam) and Barapani (Meghalaya). The study had confirmed the MLB pathogen *B. maydis* belongs to only type, the race O as regarded by the earlier workers. It may be mentioned that till date there is no any maize host differentials available for *B. maydis* to confirm the physiological race of *B. maydis* and without testing the behavior of this pathogen on differential hosts, the present identity of *B. maydis* of India as race O is probably a loosely assigned designation.

Conflict of Interests

The authors have not declared any conflict of interests.

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Effect of weed management methods on weeds and wheat (*Triticum aestivum* L.) yield

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An experiment was conducted at Holetta Agricultural Research Center to study the effect of weed management practices on weeds and yield of wheat (*Triticum aestivum* L.) during 2010 to 2011 crop seasons in randomized complete block design with three replications. The experiment comprised of twelve weed management practices as treatments. The crop was infested with *Avena fatua* L. *Cynodon dactlylon* (L) Pers, *Digitaria abbisinica* (A. Rich) Stapt and *Phalaris paradoxa* L. among grass weeds and *Amaranthus spinosus L., Caylusea abyssinica* (Feresen.) fisch and May*, C. trigyna* L.*, Conolvulus arvenesis L., Chenopodium album* L.*, Chenopodom nobile L., Corrigoala capensis* Willd.*, Galinsoga parviflora Cov. Guizotia scabra* (Vis.) Chiov.*, Medicago polymorpha L., Oxalis latifolia* H.B.K.*, Polygonum nepalense* L.*, Plantago lanceolata L., Raphanus raphanistrum* L.*, Spergula arvensis* L. and *Tagetes minuta* L. were among broad leaf weeds. The results showed that broadleaved, grass and total weed density as well as dry weight were significantly influenced by weed management practices. Hand weeding + 15 cm row spacing followed isoproturon at 1.5 kg ha^{-1} + 15 cm row spacing significantly reduced density and dry weight of weeds. Among herbicides, isoproturon + 15 cm row spacing provided better control of broadleaved and total weeds, whereas; clodinafop-propargyl + 15 cm row spacing proved better than isoproturon at 1.50 kg ha^{-1}and hand weeding + 15 cm row spacing in controlling grass weeds. Highest grain yield (2289.4 kg ha^{-1}) in was recorded in hand weeding + 15 cm row spacing followed by isoproturon at 1.50 kg ha^{-1} + 15 cm row spacing (2177.3 kg ha^{-1}). Maximum N uptake was also recorded in these treatments. Uncontrolled weed growth throughout the crop growth caused a yield reduction 57.6 to 73.2%. Post emergence herbicides (isoproturon at 1.50 kg/ha) and /or hand weeding and hoeing at tillering + narrow spacing (15 cm) can further enhance the weed suppressive effect of the crop.

Key words: Wheat, weeds, weed management methods, yield loss.

INTRODUCTION

Wheat is one of the major cereal crops grown in the Ethiopian highlands (Hailu, 2003*)*. Despite its importance in Ethiopia, the mean national yield is 1.3 tons ha^{-1} which is 24% below the mean yield of Africa and 48% below the global mean yield of wheat. It ranks 5th after teff, maize, barley and sorghum in area of production, but in terms of productivity, wheat ranks 2nd next to maize (Hailu, 2003)*.* Low yield of wheat in country is mainly caused by declining soil fertility, soil erosion, insect pests, disease and problematic weeds (Bekelle, 2004).

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Wheat crop usually suffers from stress created by weeds through competition for water, nutrients, space and sunlight (Anderson, 1983) along with interference caused by releasing toxic substances into the rhizosphere of the crop plants (Rice, 1984). Apart from increasing the production cost, they also intensify the disease and insect pest problem by serving as alternative hosts (Marwat et al., 2008). Weeds cause yield reduction up to 70% in some wheat growing areas (Tanner and Giref, 1991). To properly address the weed problem in wheat, there is a dire need of developing a package of weed control technology for the wheat growers (Marwat et al., 2008).

Manual and mechanical methods are laborious, tiresome and expensive due to increasing cost of labor, draft animals and implements and weeds cannot effectively be managed merely due to crop mimicry. Therefore, the use chemical weed control has become necessary (Marwat et al., 2008). Chemical weed control method are most ideal, practical, effective, up-to-date, time saving and economical means of reducing early weed competition and crop production losses (Ashiq et al., 2007). But, the exclusive reliance on herbicides has resulted in pollution of the environment and some weed species becoming resistant and inter- and intra-specific shifts, integrating the chemical with cultural is an excellent option for the weed control (Hassan and Marwat, 2001). Manipulating row spacing in crops that are generally planted as row crops has potential to affect weed control. The ground is shaded sooner in narrow rows and weed development is suppressed (Lyon et al., 2006). In view of these facts the present study was designed with the objectives to find out the effect of different weed managements practices on wheat yield and weeds and to assess the effect of weeds on yield attributes and yield of wheat.

MATERIALS AND METHODS

The experiment was conducted at Holleta Agricultural Research Center which is located 34 km to the west of Addis Ababa. The mean total annual rainfall is 1100 mm with mean maximum and minimum air temperature of 22.2°C and 6.13°C, respectively (EIAR, 2008).

The soil of the experiment was clay loam in texture with pH 6.65, organic carbon 2.26%, available P 14.17 mg kg^{-1} soil, total nitrogen 0.12% and cation exchange capacity, 17 Cmol kg^{-1} soils. The experiment comprised twelve treatments of three row spacing combined with two herbicides, one hand weeding at tillering and weedy check (clodinafop-propargyl at 0.105 kg ha^{-1} + 15 cm, clodinafop-propargyl at 0.105 kg ha^{-1} + 20 cm, clodinafop-propargyl at 0.105 kg ha^{-1} + 25 cm, isoproturon at 1.50 kg ha^{-1} +15 cm, isoproturon at 1.50 kg ha^{-1} +20 cm, isoproturon at 1.50 kg ha^{-1} +25 cm, hand weeding + 15 cm, hand weeding + 20 cm, hand weeding + 25 cm at tillering, weedy check + 15 cm, weedy check + 20 cm and weedy check + 25 cm). The experiment was laid out in a randomized complete block design with three replications.

Herbicides were applied as post-emergence at crop tillering stage that is, about 32 days after planting. Wheat variety HAR 604 was planted at recommended seed rate (150 kg ha^{-1}) in plots. Fertilizer was used at the rate of 64 kg N ha^{-1} and 46 kg P_2O_5 ha^{-1} through diammonium phosphate (DAP) and urea. Half of nitrogen and full amount of phosphorus was drilled in rows at the time of sowing and the remaining N through urea was applied at shoot elongation stage of crop.

Weed population and total above ground weed dry matter were recorded. Weed control efficiency (WCE) was determined by the following formula;

$$WCE = \frac{WDC - WDT}{WDC} X100$$

Where, WDC = weed dry mass from the control plot (untreated), WDT = weed dry matter from treated plot (Devasenapathy et al., 2008).

Tillers number m^{-2}, plant height (cm), grains per spike (g), thousand kernel weights (g), grain and straw yield (kg ha^{-1}) were recorded.

Harvest index (%) was calculated by the following formula;

$$HI = \frac{Grain\ yield}{Total\ aboveground\ dry\ biomass\ yield} X100$$

Total nitrogen uptake by the wheat crop and associated weed was determined by Kjeldhal digestion method (Jackson, 1958). The uptake of nitrogen (kg ha^{-1}) was calculated as:

$$Uptake\ of\ N = \frac{N(\%)\ in\ the\ material\ X\ dry\ weight\left(\frac{kg}{ha}\right)}{100}$$

Crop yield loss due to weeds was calculated as follows:

$$Yield\ loss = \frac{MY - YT}{MY} X100$$

Where, MY= maximum yield from a treatment, YT = yield from a particular treatment.

Weed count were subjected to square root transformation, $\left(\sqrt{(X+0.5)}\right)$ to have normal distribution of the data. Analysis of variance and mean separation tests were applied following the randomized complete block design procedure as described by Gomez and Gomez (1984) using the SAS computer software package version 9.2.

RESULTS AND DISCUSSION

Weed composition of the experimental site

The crop was infested with *Avena fatua* L. *Cynodon dactlylon* (L) Pers, *Digitaria abbisinica* (A. Rich) Stapt and *Phalaris paradoxa* L. among grass weeds and *Amaranthus spinosus L. Caylusea abyssinica (*Feresen.) fisch and May*, C. trigyna* L.*, Conolvulus arvenesis L., Chenopodium album* L.*, Chenopodom nobile L., Corrigoala capensis* Willd.*, Galinsoga parviflora Cov. Guizotia scabra* (Vis.) Chiov.*, Medicago polymorpha L., Oxalis latifolia* H.B.K.*, Polygonum nepalense* L.*, Plantago*

Table 1. Effect of weed management practices on density (m^{-2}) broadleaved, grass and total weeds.

Weed management practices	Wee density (m^{-2})		
	Broad	Grass	Total
Clodinafop-propargyl 0.105 kg ha^{-1} + 15 cm	5.58(30.67)	0.70(0.00)	5.58(30.67)
Clodinafop-propargyl 0.105 kg ha^{-1} + 20 cm	6.96 (48.00)	1.86(4.00)	7.17(52)
Clodinafop-propargyl 0.105 kg ha^{-1} + 25 cm	8.29 (68.33)	2.47(5.67)	8.63(74)
Isoproturon 1.50 kg ha^{-1} + 15 cm	2.27 (4.67)	1.86 (3.00)	2.85(7.67)
Isoproturon 1.50 kg ha^{-1} + 20 cm	3.08 (9.00)	2.40(5.33)	3.85(14.33)
Isoproturon 1.50 kg ha^{-1} + 25 cm	4.62 (21.00)	3.34(10.68)	5.67(31.68)
Hand weeding at tillering +15 cm	1.94 (3.33)	2.03(3.67)	2.72(7.00)
Hand weeding at tillering + 20 cm	2.34 (5.00)	2.20(4.33)	3.13(9.33)
Hand weeding at tillering + 25 cm	2.96 (8.33)	2.86(7.69)	4.06(16.00)
Weedy check + 15 cm	5.77 (33.00)	3.39(11.00)	6.66(44.00)
Weedy check + 20 cm	7.10 (50.00)	4.29(18.00)	8.27(68.00)
Weedy check + 25 cm	8.23(67.34)	5.11(25.67)	9.67(83.00)
LSD (0.05)	0.44	0.308	0.42
CV(%)	5.21	6.71	4.39

Figures in parenthesis are the original values, LSD =least significant difference, CV =coefficient of variation.

lanceolata L., Raphanus raphanistrum L., *Spergula arvensis* L. and *Tagetes minuta* L. were among broad leaf weeds. Out of total weeds present in the experimental field 80% were broadleaved while 20% were grasses.

Weed density

The data (Table 1) showed a significant difference in broadleaved, grass and total weed density due to weed management practices. The lowest broadleaved weeds density (3.33 m^{-2}) was recorded when wheat was sown at 15 cm row spacing + hand weeded followed isoproturon at 1.50 kg ha^{-1} + row spacing of 15 cm (4.67 m^{-2}) and 20 cm row spacing + hand weeding (2.34 m^{-2}) but no significance difference were observed among them whereas, the highest number of broadleaved weeds (67.34 m^{-2}) was observed when wheat was sown in 25 row spacing without controlling weeds (Table 1). However, application of clodinafop-propargyl 0.105 kg ha^{-1} failed to reduce significantly as compared to weedy check at the same row spacing. These findings are in agreement with the work of Marwat et al. (2008) and Ashrafi (2009) who reported that integration of closer row spacing with broad spectrum herbicides reduce weed population as compared to weedy check.

Unlike broadleaved weeds, the results in Table 1 revealed that application of clodinafop-propargyl at 0.105 kg ha^{-1} + 15 cm row spacing had no grass weeds whereas, the highest (25.67 m^{-2}) grass weeds density was recorded in 25 cm row spacing without controlling the weeds. In general, application of clodinafop-propargyl + 15 cm row spacing proved more effective in reducing the grass weed density. These finding are in agreement with the work of Jamil et al. (2003) who reported that herbicide application with narrow row spacing suppressed weeds population more effectively than of weedy check with wider spacing.

Moreover, a minimum total weeds density (7.00 m^{-2}), observed in plots having 15 row spacing and hand weeded followed by isoproturon at 1.50 kg ha^{-1} + 15 cm row spacing (2.85m^{-2}) and hand weeded + 20 cm row spaced (9.33 m^{-2})(Table 1) but no significant difference was recorded among them. The better control of both broadleaved and grassy weeds through hand weeding + 15 cm row spacing and isoproturon at 1.50 kg ha^{-1} + 15 cm row spacing resulted in lower total weed density. These finding are in agreement with the work of Jamil et al. (2003) who reported that broad spectrum herbicide with narrow row spacing suppressed weeds population more effectively than weedy check with wider spacing.

Weeds dry weight

Significant variation in weed dry weight existed between treatments (Table 2). The significantly lowest (4.07g m^{-2}) weed dry weight resulted from hand weeding and isoproturon at 1.50 kg ha^{-1} + 15 cm row spacing (4.10 g m^{-2}) as compared to other treatments however, no significance difference between them. Minimum total weed dry weight recorded in the combination of 15 cm row spacing and hand weeding and isoproturon at 1.50 kg ha^{-1} might be due to hand weeding and broad spectrum (broadleaved and grassy weeds) weed control

Table 2. Effect weed management practices on total weed dry weight (g m^{-2}) and weed control efficiency (%).

Weed management practices	Dry weight	WCE (%)
Clodinafop-propargyl 0.105 kg ha^{-1} + 15 cm	8.03	67.1
Clodinafop-propargyl 0.105 kg ha^{-1} + 20 cm	14.23	41.7
Clodinafop-propargyl 0.105 kg ha^{-1} + 25 cm	19.87	18.6
Isoproturon 1.50 kg ha^{-1} + 15 cm	4.10	83.4
Isoproturon 1.50 kg ha^{-1} + 20 cm	6.33	65.8
Isoproturon 1.50 kg ha^{-1} + 25 cm	13.03	46.6
Hand weeding at tillering +15 cm	4.07	83.2
Hand weeding at tillering + 20 cm	8.27	66.1
Hand weeding at tillering + 25 cm	11.47	52.9
Weedy check + 15 cm	10.37	57.5
Weedy check + 20 cm	16.30	33.2
Weedy check + 25 cm	24.40	0.0
LSD (0.05)	1.14	4.62
CV(%)	5.69	5.31

LSD =least significant difference, CV =coefficient of variation.

that resulted plus less space for weed development, better competition of wheat crop for development resource, crop growth rate, early space covering, and light interception in narrow row as compare to wide row spacing. These results were in agreement with the work of Iqbal (2002) who verified that combination of closer spacing with broad spectrum herbicide that reduced the weed dry weight as compared to narrow spectrum herbicide and weedy check.

Weed control efficiency

Effect of weed management practices on weed control efficiency was significant (Table 2). The highest weed control efficacy (83.2%) was recorded in hand weeding followed by isoproturon at 1.50 kg ha^{-1} (83.4 %) + 15 cm row spacing whereas, the lowest (0%) was recorded in weedy check + 25 row spacing. This might be due the collective effect of hand weeding and/isoproturon at 1.50 kg ha^{-1} and narrow spacing (15 cm).

Yield and yields attributes

Effect of weed management practices on tiller number m^{-2} and grains per spike (g) were significance however, plant height was not significance influenced by different weed management methods. The results (Table 3) revealed that maximum tillers were recorded in hand weeding + 15 cm row spacing followed by isoproturon at 1.50 kg ha^{-1}+ 15 cm row spacing whereas minimum number of tillers were recorded in weedy check + 25 cm row spacing. Furthermore, the highest grains per spike (23.73 g) were recorded in hand weeding + row spacing of 15 cm followed by isoproturon at 1.50 kg ha^{-1} + 15 cm row spacing (22.40 g) whereas, the minimum was observed in weedy check + 25 cm row spacing (5.5 g).

Similarly, effect of weed management practices on 1000 kernel weight, grain and straw yield were significant. Contrary, the combination of isoproturon at 1.50 kg ha^{-1} and hand weeding + 25 cm gave higher thousand kernel weights and might be due to effective weed control and more space available for better light interception that helped to improve the photosynthetic efficiency of the crop thus more availability of assimilates for the crop/ grain development as compared to narrow row spacing and lower grain per spike that resulted in heavier grain. Similar result was also reported by Iqbal (2003).

The overall grain yield in the experiment was low (Table 4) due to severe infestation of yellow rust in the crop. Results given in Table 4 showed that, the highest grain yield (2289.4 kg ha^{-1}) was recorded in hand weeding + 15 cm row spacing followed by isoproturon at 1.5 kg ha^{-1} + 15 cm row spacing (2177.3 kg ha^{-1}) whereas the lowest was recorded in control treatment + 25 cm row spacing (614.4 kg ha^{-1}). This might be due to effective weed control in plots treated with hand weeding and broad spectrum herbicides in conjunction with narrow row spacing wherein; the cumulative effect resulted in increased number of tillers and grains per spike which contributed to increased yield, despite reduced 1000 grain yield.

Similar to the effect on grain yield, the straw yield was also significantly affected by weed management practices. Effect of weed management practices on harvest index, nitrogen uptake by crop (grain and straw) and associated weeds (broad and grass) were significant. The highest harvest index was recorded in a plot treated

Table 3. Effect of weed management practices on plant height (cm), tiller number (m^{-2}) and grain per spike (g).

Weed management practices	Height (cm)	Tiller (m^{-2})	Gain per spike (g)
Clodinafop-propargyl 0.105 kg ha^{-1} + 15 cm	106.7	211.0	14.1
Clodinafop-propargyl 0.105 kg ha^{-1} + 20 cm	103.7	197.0	12.5
Clodinafop-propargyl 0.105 kg ha^{-1} + 25 cm	98.3	184.0	10.7
Isoproturon 1.50 kg ha^{-1} + 15 cm	104.0	238.3	22.4
Isoproturon 1.50 kg ha^{-1} + 20 cm	103.0	218.0	20.4
Isoproturon 1.50 kg ha^{-1} + 25 cm	104.3	204.3	17.5
Hand weeding at tillering +15 cm	102.0	247.0	23.7
Hand weeding at tillering + 20 cm	102.7	225.7	21.5
Hand weeding at tillering + 25 cm	105.3	207.3	18.6
Weedy check + 15 cm	99.2	184.3	8.5
Weedy check + 20 cm	103.0	166.0	7.3
Weedy check + 25 cm	97.667	149.0	5.5
LSD (0.05)	NS	6.11	0.75
CV(%)	6.16	1.78	2.90

LSD = least significant difference, CV =coefficient of variation.

Table 4. Effect of weed management practices on 1000 kernel weight (g) grain and straw yield (kg ha^{-1}).

Weed management practices	1000 kernel weight (g)	Grain yield (kg ha^{-1})	Straw yield (kg ha^{-1})
Clodinafop-propargyl 0.105 kg ha^{-1} + 15 cm	23.30	1413.00	3878.7
Clodinafop-propargyl 0.105 kg ha^{-1} + 20 cm	28.53	1310.50	3728.9
Clodinafop-propargyl 0.105 kg ha^{-1} + 25 cm	31.10	1171.93	3552.2
Isoproturon 1.50 kg ha^{-1} + 15 cm	27.30	2177.30	5481.9
Isoproturon 1.50 kg ha^{-1} + 20 cm	31.33	2007.43	5287.4
Isoproturon 1.50 kg ha^{-1} + 25 cm	34.83	1896.47	5117.2
Hand weeding at tillering +15 cm	30.53	2289.40	5698.2
Hand weeding at tillering + 20 cm	33.27	2107.83	5355.9
Hand weeding at tillering + 25 cm	36.60	1910.10	5241.0
Weedy check + 15 cm	17.50	970.87	3195.9
Weedy check + 20 cm	18.20	872.30	3110.2
Weedy check + 25 cm	23.93	614.37	2472.7
LSD (0.05)	1.48	51.07	266.4
CV(%)	3.12	1.93	3.62

LSD =least significant difference, CV =coefficient of variation.

with hand weeding (28.66%), isoproturon at 1.50 kg ha^{-1} in + (15 cm) row spacing whereas, the lowest was in weed check plot with wider (25 cm) row spacing (Table 5).

The maximum N uptake (115.67 kg ha^{-1}) was recorded with the combination of hand weeding + 15 cm row spacing followed by isoproturon at 1.50 kg ha^{-1} + 15 cm row spacing (109.34 kg ha^{-1}) whereas; it was minimum (34.33 kg ha^{-1}) in weedy check + 25 cm row spacing (Table 5). The significant variation in N uptake by wheat crop might be due to better control of weeds that enhanced growth and development of the crop. Thus, the reduced weed competition for nutrients favored the crop against weeds resulting in increased N uptake. These findings are in agreement with the work of Nadeem et al. (2006) who reported weed management practices reduced the N-uptake by weeds in wheat. Similarly, Kumar and Agarwal (2010) also reported higher N uptake in weed management treated plots. Moreover, the weed management practices were also significantly affected N uptake by weeds. These finding are in agreement with the work of Abouziena et al. (2008) and Kumar and Agarwal (2010) who observed that weeds compete very effectively with the crop for available nitrogen to the point that the reduction in yields from weed competition were generally accompanied by reduction in protein content as well. Maximum (13.34 kg ha^{-1}) was recorded in control treatment + 25cm row spacing (Table 5) which might be

Table 5. Effect of row spacing and weed management practices on harvest index (%), Nitrogen uptake by crop and its associated weeds (kg ha^{-1}).

Weed management practices	HI (%)	N uptake by crop (kg ha^{-1})	N uptake by weeds (kg ha^{-1})
Clodinafop-propargyl 0.105 kg ha^{-1} + 15 cm	26.71	71.33	6.07
Clodinafop-propargyl 0.105 kg ha^{-1} + 20 cm	26.01	64.33	7.07
Clodinafop-propargyl 0.105 kg ha^{-1} + 25 cm	24.82	57.33	8.10
Isoproturon 1.50 kg ha^{-1} + 15 cm	28.43	109.34	3.67
Isoproturon 1.50 kg ha^{-1} + 20 cm	27.53	91.35	4.93
Isoproturon 1.50 kg ha^{-1} + 25 cm	27.04	80.33	5.53
Hand weeding at tillering +15 cm	28.66	115.67	2.87
Hand weeding at tillering + 20 cm	28.25	99.67	3.53
Hand weeding at tillering + 25 cm	26.73	89.67	4.40
Weedy check + 15 cm	23.30	49.67	8.47
Weedy check + 20 cm	21.91	41.33	10.93
Weedy check + 25 cm	19.96	34.33	13.43
LSD (0.05)	1.06	6.03	1.04
CV(%)	2.42	4.72	9.33

LSD = Least Significant Difference, CV = Coefficient of variation.

Table 6. Effect of weeds on yield of wheat crop under different weed management practices.

Weed management practices	Relative yield loss (%)
Clodinafop-propargyl 0.105 kg ha^{-1} + 15 cm	38.3
Clodinafop-propargyl 0.105 kg ha^{-1} + 20 cm	42.8
Clodinafop-propargyl 0.105 kg ha^{-1} + 25 cm	48.8
Isoproturon 1.50 kg ha^{-1} + 15 cm	4.9
Isoproturon 1.50 kg ha^{-1} + 20 cm	12.3
Isoproturon 1.50 kg ha^{-1} + 25 cm	17.2
Hand weeding at tillering +15 cm	0.0
Hand weeding at tillering + 20 cm	7.9
Hand weeding at tillering + 25 cm	16.6
Weedy check + 15 cm	57.6
Weedy check + 20 cm	61.9
Weedy check + 25 cm	73.1

due to higher weed population in control treatment and the avialability of wider space for weed development.

Effect of weeds on yield loss in wheat

While comparing the loss in yield due to the weed management practices, the lowest loss in yield (4.9%) was recorded in isoroturon at 1.50 kg ha^{-1} + 15 cm row spacing as compared to the highest yield obtained in hand weeding done + 15 cm spaced crop. This was followed by hand weeding + 20 cm row spacing (7.9%) and isoroturon at 1.25 kg ha^{-1} (12.3%) whereas; it was highest (73.2%) in weedy check with 25 cm row spacing (Table 6).

Conclusions

Combination of hand weeding + 15 cm row spacing reduced broadleaved weed density, total weed density and dry weight of weeds followed by isoproturon at 1.50 kg ha^{-1} with 15 cm row spacing. However density of grassy weeds was lower in plot treated with clodinafop-propagyl at 0.105 kg ha^{-1} + 15 cm row spacing. These treatments also increased yield and yield attributes and uptake of nitrogen of wheat significantly. Uncontrolled weed growth throughout the crop growth caused a yield reduction 57.6 to 73.2%. Post emergence herbicides (isoproturon at 1.50 kg/ha) and /or hand weeding and hoeing at tillering + narrow spacing (15 cm) further enhanced the weed suppressive effect of the crop.

However, because of the agro ecology and seasonal variation, further research is necessary in order to provide more accurate recommendation.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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